OCT 1955
LIBRARY
POFI
FISH & WILDLIFE
SERVICE

EXPEDITION REPORTS
Q115
G7
V. 15
Discovery Repts.
1920-1959
V. 15, 1590
ISSUED TO
DATE

EXPEDITION REPORTS
Q115
G7
V, 15
Discovery Reports
1920-1959
V. 15, 1590

LIBRARY
BUREAU OF COMMERCIAL FISHERIES
U. S. FISH AND WILDLIFE SERVICE
P. O. BOX 3830

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

# DISCOVERY REPORTS

Issued by the Discovery Committee
Colonial Office, London
on behalf of the Government of the Dependencies
of the Falkland Islands

VOLUME XV

OCT 1955
LIBRARY
POFI
FISH & WILDLIFE
SERVICE

Q115.D7
V.15
1590

CAMBRIDGE
AT THE UNIVERSITY PRESS
1937

PRINTED IN GREAT BRITAIN BY WALTER LEWIS, M.A., AT THE UNIVERSITY PRESS, CAMBRIDGE

# CONTENTS

THE HYDROLOGY OF THE SOUTHERN OCEAN (published 24th March, 1937)

By G. E. R. Deacon, B.Sc.

Introduction . . . . . . . . . . . . . . . . . . *page* 3
Antarctic Surface Water . . . . . . . . . . . . . . . . 7
Sub-Antarctic Water . . . . . . . . . . . . . . . . 46
Subtropical Water . . . . . . . . . . . . . . . . . 72
The Warm Deep Layer . . . . . . . . . . . . . . . . 80
Antarctic Bottom Water . . . . . . . . . . . . . . . . 106
Appendix I . . . . . . . . . . . . . . . . . . 118
References . . . . . . . . . . . . . . . . . . 120
Note on the Plates . . . . . . . . . . . . . . . . . 123
Plates I–XLIV . . . . . . . . . . . . . . . *following page* 124

NOTE ON THE DYNAMICS OF THE SOUTHERN OCEAN (published 17th March, 1937)

By G. E. R. Deacon, B.Sc. . . . . . . . . . . . . . . . . *page* 125

NEW SPECIES OF MARINE MOLLUSCA FROM NEW ZEALAND (published 16th March, 1937)

By A. W. B. Powell

Introductory Note . . . . . . . . . . . . . . . . . *page* 155
The Molluscan Fauna of Northern New Zealand . . . . . . . . . . 156
Material Examined . . . . . . . . . . . . . . . . . 157
List of Mollusca Collected . . . . . . . . . . . . . . . 158
Systematic Account . . . . . . . . . . . . . . . . . 163
Plates XLV–LVI . . . . . . . . . . . . . . *following page* 222

## THE AGE OF FEMALE BLUE WHALES AND THE EFFECT OF WHALING ON THE STOCK (published 19th May, 1937)

By Alec H. Laurie, M.A.

INTRODUCTION . . . . . . . . . . . . . . . . . . . . *page* 225
BIOLOGICAL NOTES . . . . . . . . . . . . . . . . . . 230
THE RATE OF BREEDING . . . . . . . . . . . . . . . . . 239
AGE DETERMINATION . . . . . . . . . . . . . . . . . . 243
THE AGE AT PHYSICAL MATURITY . . . . . . . . . . . . . . 259
PRESENT SPAN OF LIFE . . . . . . . . . . . . . . . . . 260
POPULATION AND RECRUITMENT . . . . . . . . . . . . . . . 261
AVERAGE LENGTH OF BLUE FEMALES . . . . . . . . . . . . . 265
INCREASE OF IMMATURE WHALES IN THE CATCH . . . . . . . . . 266
SUMMARY . . . . . . . . . . . . . . . . . . . . . . 267
LITERATURE CITED . . . . . . . . . . . . . . . . . . 269
APPENDIX I: BLUE WHALES TAKEN IN THE ANTARCTIC SINCE 1904–5 AND OFF THE COAST OF AFRICA SINCE 1910 . . . . . . . . . . . . . . . . . . . . 270
APPENDIX II: PARTICULARS OF THE COLLECTIONS OF OVARIES, 1934–6 . . . . . . 271

[*Discovery Reports. Vol. XV, pp.* 1–124, *Plates I–XLIV, March,* 1937.]

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

# THE HYDROLOGY OF THE SOUTHERN OCEAN

By

G. E. R. DEACON, B.Sc.

# CONTENTS

Introduction . . . . . . . . . . . . . . . . . . . *page* 3

Antarctic surface water . . . . . . . . . . . . . . . . 7
  The movements of Antarctic surface water . . . . . . . . . 10
  The East Wind Drift . . . . . . . . . . . . . . . 14
  The Antarctic convergence . . . . . . . . . . . . . 20
  The West Wind Drift . . . . . . . . . . . . . . . 24
  The depth of the surface layer . . . . . . . . . . . 40
  Temperature and salinity . . . . . . . . . . . . . 42

Sub-Antarctic water . . . . . . . . . . . . . . . . 46
  The surface current . . . . . . . . . . . . . . . 50
  The subtropical convergence . . . . . . . . . . . . 56
  The subsurface current . . . . . . . . . . . . . . 63
  The Antarctic intermediate current . . . . . . . . . . 66
  Temperature and salinity . . . . . . . . . . . . . 70

Subtropical water . . . . . . . . . . . . . . . . . 72
  The movements of subtropical water . . . . . . . . . . 73
  Temperature and salinity . . . . . . . . . . . . . 80

The warm deep layer . . . . . . . . . . . . . . . . 80
  The deep currents in the southern part of the Atlantic Ocean . . . 87
  The deep currents in the southern part of the Indian Ocean . . . . 96
  The deep currents in the southern part of the Pacific Ocean . . . . 99

Antarctic bottom water . . . . . . . . . . . . . . . 106
  The movements of Antarctic bottom water . . . . . . . . . 110

Appendix I. . . . . . . . . . . . . . . . . . . 118

References . . . . . . . . . . . . . . . . . . 120

Note on the Plates . . . . . . . . . . . . . . . . 123

Plates I–XLIV . . . . . . . . . . . . *following page* 124

# THE HYDROLOGY OF THE SOUTHERN OCEAN

By G. E. R. Deacon, B.Sc.

(Text-figs. 1–22; Plates I–XLIV)

## INTRODUCTION

THE series of observations which the Discovery Committee has been conducting for some years past on the hydrology and plankton of the South Atlantic and neighbouring parts of the Indian and Pacific Oceans was extended by a circumpolar cruise in 1932–3 to include the whole of the Southern Ocean. The work in the Indian and Pacific Sectors was carried out entirely during the winter months, and the data are therefore not sufficient for a complete examination of the hydrology, but so much has been discovered that is of immediate importance to those who are continuing the work and to those who are studying the plankton, that the following account has been prepared.

The report is based largely upon the observations made during the second commission of the R.R.S. 'Discovery II', when the Antarctic Continent was circumnavigated, but all the data collected during the first commission and by the Committee's other vessels have been taken into consideration. In one or two instances a preliminary use has also been made of the material collected during the third voyage which was successfully concluded in 1935.

The author has already given a general account of the hydrology of the South Atlantic Ocean, but since some of the problems of this ocean have been brought much nearer solution by the examination of other aspects of the same problems in the Indian and Pacific Oceans, this report has a good deal to add to the previous one. It has also been found necessary to extend the accounts of some of the Atlantic currents in view of their importance to the world-wide movements.

Throughout the whole of the Southern Ocean the meridional circulation of water is very similar to the Atlantic circulation illustrated in Fig. 1. On all sides of the pole the Antarctic water spreads northwards in a shallow layer at the surface until it reaches the Antarctic convergence where it plunges abruptly to a deeper level to continue its northward movement as the Antarctic intermediate current.

The observations made during the circumpolar cruise have shown that the latitude of the convergence is determined by the movements of the deep and bottom waters. In each sector of the Southern Ocean there is a warm deep current moving towards the south; the current is almost horizontal until it approaches the Antarctic region, but then climbs steeply towards the surface over a current of Antarctic bottom water which sinks in the opposite direction, and continues towards the south at a much lesser depth

The steep slope of the deep layer decides the position of the Antarctic convergence, along which the Antarctic current sinks. The position of the steep slope itself is determined by the northward progress made by the bottom current; this has been found to depend chiefly on the topography of the sea-bottom and the distance from the source of the bottom water, but there may be other governing factors.

The evidence that a warm deep current flows southwards in each of the three main oceans is itself an important feature of this report. The existence of such a current in the Atlantic Ocean has not been disputed since it was first demonstrated by Merz and Wüst (1922), but opinion as to its presence in the Indian Ocean is divided (Möller, 1933; Thomsen, 1933), and Sverdrup (1931) is convinced of its absence in the Pacific Ocean. Our observations give evidence of the current in each of these oceans, but they show that it does not necessarily carry the most saline deep water. In the southern part of the Indian Ocean, for example, the most saline water belongs to an eastward current from the Atlantic Ocean, and in the Pacific Ocean to a current from probably both the Indian and Atlantic Oceans.

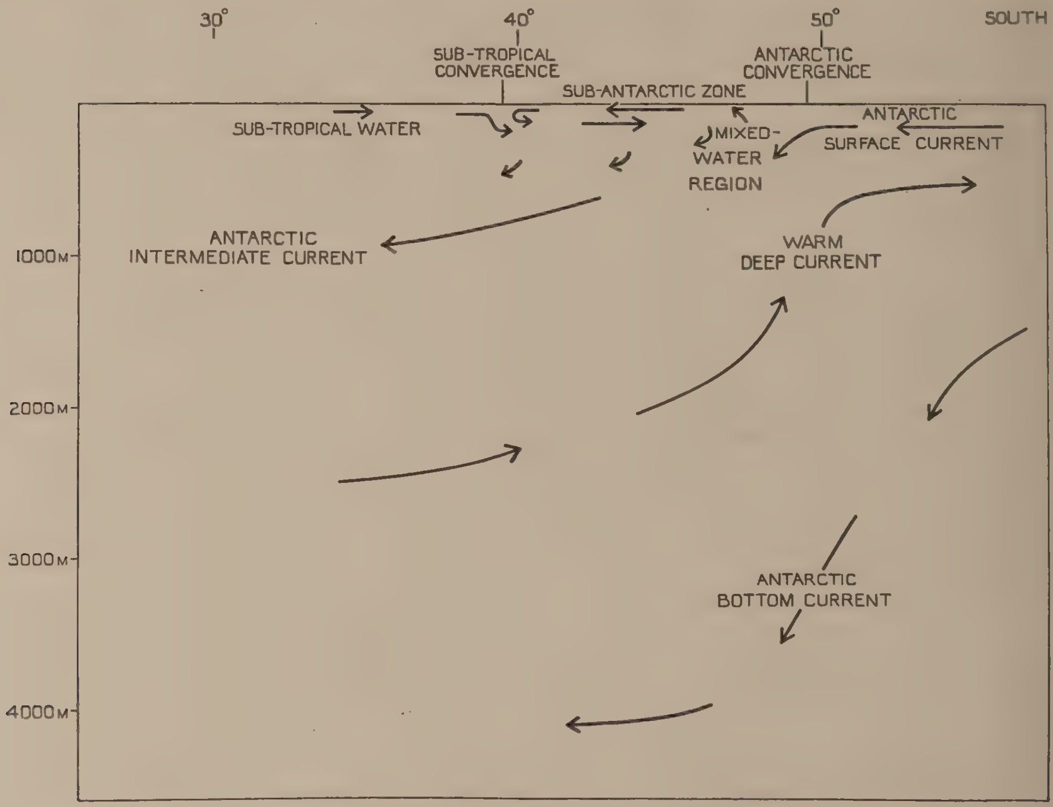

30°
40°
50°
SOUTH
SUB-TROPICAL CONVERGENCE
ANTARCTIC CONVERGENCE
SUB-ANTARCTIC ZONE
SUB-TROPICAL WATER
ANTARCTIC SURFACE CURRENT
MIXED-WATER REGION
ANTARCTIC INTERMEDIATE CURRENT
WARM DEEP CURRENT
ANTARCTIC BOTTOM CURRENT
1000M
2000M
3000M
4000M

Fig. 1. The vertical circulation of water in the South Atlantic Ocean.

The circumpolar cruise has also given rise to a new conception of the Antarctic bottom current. The bottom water appears to be formed not all round the Antarctic

Continent, as is generally supposed, but only in the south-western and western parts of the Weddell Sea. From this region it spreads towards the east, and although it is continually mixing with the deep water and spreading towards the north it is not reinforced by any appreciable addition of cold surface or shelf water. Its temperature and salinity increase continuously towards the east from the Weddell Sea through the Indian and Pacific Oceans to the west coast of Graham Land, and it thus follows that there is a very sharp difference in the character of the water on the two sides of this promontory. The oxygen content of the bottom water shows a continuous decrease along the same path. A small part of the bottom water is formed between the South Orkney Islands and the South Shetland Islands in the same way as the Arctic bottom water south of Greenland and north and south of Jan Mayen (Nansen, 1912), by a convection which reaches from the surface to the bottom in winter; the greater part is, however, formed by the sinking of highly saline shelf water in the south-western part of the Weddell Sea.

New information has also been obtained as to the nature of the subtropical convergence, which appears to be formed as a result of the balance between a northward movement in the sub-Antarctic water and a southward movement in the subtropical water. Its position has been found, in some parts of the ocean at least, to be subject to much greater variations than that of the Antarctic convergence; it advances towards the south in summer, recedes to the north in winter, and in the central part of the Atlantic Ocean it has other irregular movements with a range of as much as 6° of latitude. It has also been found that the convergence is not necessarily the boundary between the easterly current caused by the west winds of the forties and the westerly current caused by the trade winds farther north; it lies within the region of westerly winds, and the water in the southern part of the subtropical zone generally flows eastwards.

It is clearly recognized that much of the value of this report lies in the vertical sections at the end of it, but it was thought unnecessary to describe the temperature and salinity distribution in each section in detail, since the diagrams themselves are the best way of giving this information. The lines along which the observations were made are shown in Plate I. As many of the actual observations are reproduced in the diagrams as could be included without causing confusion, but most of the data from the first 400 m. have had to be left out. The data collected from the depths of 0, 10, 20, 30, 40, 50, 60, 80, 100, 150, 200, 300, and 400 m. were, however, used in the production of the original drawings, which are twice the size of the finished plates. The clearness of the diagrams is largely the result of the careful work of Miss E. C. Humphreys, who prepared my drawings for reproduction.

Whilst I have endeavoured in writing this report to make suitable acknowledgment of my indebtedness to the earlier workers on the subject, it is almost impossible to do them complete justice. In the relatively short time at my disposal I have not been able to read carefully through all the original reports and papers which have been published, but have only been able to make short abstracts and have had to confine my attention principally to the excellent summary accounts given by Schott (1926), Defant (1928), Wüst (1928, 1929), and Möller (1929). It is most unfortunate that, having to complete the manuscript before leaving on the fourth commission of the 'Discovery II', I have not been able to make use of Schott's most comprehensive *Geographie des Indischen und Stillen Ozeans* (1935). For more modern representations of the temperature, salinity, and current distributions than those referred to in this report, the reader should turn to that work. I have also been unable to make use of the Meteor data which, though published in Bd. IV, Part 2, of the Meteor Reports, dated 1932, were not available in this country until March 1935—the issue of this part having presumably been delayed.

It would be ungrateful to publish this report without making some acknowledgment to my colleagues who helped to make the observations on which it is based. The perfect suitability of the ship for her purpose must also be emphasized. To make a success of the circumpolar cruise it was necessary to be able to steam, without refuelling, for about 8000 miles at an average speed of 9 knots under the notoriously stormy conditions of the Southern Ocean, and to have a ship and gear which would allow complete series of observations to be made in anything short of a hurricane, and also permit the chemical examination of the water samples with an accuracy as great as that which is attained in a well-found shore laboratory. The 'Discovery II' must have fulfilled the most optimistic wishes of her designers and builders, and, largely owing to the excellence of the scientific equipment, planned after long experience by Dr S. Kemp, F.R.S., the Director of Research, the work was rarely interrupted.

The success of the cruise was also due in a large measure to the efforts of the ship's personnel. The skill of the Captain, the late Commander W. M. Carey, R.N., and his officers in handling the ship, made the work almost uneventful; though the water-bottles were often lowered at great risk they were invariably hauled back safely. Apart from this side of the work their difficulties must have been enormous. As Professor Schott (1933, p. 342), in a short description of the cruise, says: "To give a suitable account of what it means to push southwards to the pack-ice boundary in the long winter nights with very little daylight, stopping the ship in rough weather and high seas to make scientific observations, would take more space than is available here."

Much credit is also due to my colleagues on the scientific staff, Mr D. D. John who was in charge of the scientific work, Mr J. W. S. Marr, Mr G. W. Rayner, and Dr F. D. Ommanney; their patience with the instruments and gear was unbounded. The services of Mr A. Saunders, the laboratory assistant, on deck and in the laboratory were invaluable. The efficiency and cheerfulness of the seamen when handling the gear under the worst conditions in winter were most remarkable.

One of the smallest services provided by the Chief Engineer, but one of vital importance to the hydrological work, was the supply of distilled water; even when the ship was almost lost in a cloud of spray it contained no trace of chloride.

The continuous thermograph was found to be most useful; it continued to give a reliable temperature record when it was impossible to go on deck to make other observations. The value of the continuous record was greatly increased by the complete records of distances and positions given by the navigator, Lt. A. L. Nelson, R.N.R.

## ANTARCTIC SURFACE WATER

The Antarctic surface layer of the South Atlantic Ocean has been described by the author in an earlier report (1933). It is a shallow layer of cold water 100–250 m. in thickness lying above a deeper and more extensive layer of warm highly saline water. In winter it is practically homogeneous, but in summer, owing to the greater effect on the surface water of the radiation from the sun and thaw-water from melting ice and snow, there is a surface stratum which is much warmer and less saline than the rest of the layer. The observations made during the circumpolar cruise in 1932–3 show that there is a similar layer round the whole of the Southern Ocean; it is bounded on the south by the Antarctic Continent, and on the north by the Antarctic convergence. The extent of the zone is shown on a circumpolar chart in Fig. 4 (p. 19).

In some of the shelf-seas neighbouring the Antarctic Continent the surface layer is not so well defined. The observations made by Brennecke (1921, p. 99) at Deutschland St. 125, near Vahsel Bay, south of the Weddell Sea, and our observations in the southern part of the Ross Sea (Sts. RS 19–29) and the Bransfield Strait (Clowes, 1934), show that in these localities there are basins from which the warm deep water is wholly or partly excluded by submarine ridges; in such basins the water is completely or almost homogeneous from the surface to the bottom in winter, and the surface water differs from the deep water only in summer. At Sts. 1015–17 in section 1 (Plate II) the conditions are typical of the Antarctic Zone, and the surface layer is separated from the warm deep layer by a sharp discontinuity in which the temperature, salinity, and oxygen content change rapidly with depth; but at St. 1014 in the northern part of the Bransfield Strait the properties of the surface water are not very different from those of the deep water. Near the Antarctic Continent there are probably many other small basins with no warm deep water and they are even found relatively far north in the Antarctic Zone, notably in Douglas Strait between Cook and Thule Islands in the South Sandwich group (Kemp and Nelson, 1931, pp. 178–83), and on a smaller scale in Moränen and Drygalski Fjords in South Georgia (Hart, 1934, pp. 213–14, and Mosby, 1934, pp. 109–111).

The observations made during the circumpolar cruise give some indication of the length of the season in which the surface stratum is warmer than the rest of the layer. The data from the southern part of the Pacific Ocean show that in September and October the layer is almost homogeneous: the only indication of a division into surface and cold strata was found at St. 961 in section 15 (Plates XXXIV–XXXVI), but the temperature difference, 0·8° C., was too large to be regarded as due to the warming of the water at the surface, and it was more probably a sign of a southward current at the surface. The observations made along section 1 in the early part of November show that a distinct surface stratum had developed. At Sts. 1015–16 in 59–57° S the surface water was 0·1 to 0·2° C. warmer than the coldest water at 80–100 m., and at St. 1017 in 56° S the difference was as much as 0·7° C. The temperature curves for a station north of Prince Olaf Harbour, South Georgia (Deacon, 1933, fig. 14), show that in approximately 53° S the surface stratum begins to form in about the middle of October.

A comparison of these data with the observations made farther south—for the most part south of 60° S—in the Pacific Ocean, indicates that the surface water in the northern part of the zone is the first to be raised above its winter temperature. The earlier formation of the stratum in the north is no doubt caused by the greater amount of radiation falling on the northern part of the zone.

It is also natural to conclude that the water in the southern part of the zone will be the first to cool to its winter temperature at the end of summer. The first sign of the approach of winter was noted in the middle of March at St. 1154 (section 7, Plates X–XII) in 69° 20′ S, 9° 34′ E. The surface water was cooled to a temperature of −1·57° C., whilst the water at 60 m.—probably the remains of the warm surface stratum of the previous summer—was not colder than −1·10° C. The observations made at this time north of the Antarctic Circle suggest that the surface water had not begun to cool, and even as late as the middle of March the radiation and conduction of heat from the surface appears to be balanced by the heat which is being absorbed. At Sts. 1156 and 1158 the surface water was 2·19 and 2·39° C. warmer than the cold stratum, and the low salinity of the surface water at St. 1158 suggests the nearness of melting ice.

The observations in sections 8 and 9 (Plates XIII–XVIII) in the Indian Ocean show that by the second half of April and the first half of May all the Antarctic water was cooling. As the surface water loses heat—principally by radiation—it becomes heavier and sinks to mix with the deeper water. At first the mixing is confined to the surface stratum, but as the density of this water approaches that of the cold stratum, it extends throughout the whole layer which in time becomes homogeneous. At the stations south of 63° S near the end of April the water was coldest at the surface, but at those farther north the surface stratum was still 1·1 to 1·7° C. warmer than the cold stratum.

South of 59–60° S in the region south of Australia and New Zealand the surface layer was cooled right through to an even temperature; but farther north, although the observations were made in the second half of May and June, the surface water was still warmer than the lower stratum. The difference was most marked near the convergence: at Sts. 883 and 891 (sections 10 and 11, Plates XIX–XXIV) the first 100 m. of water was 1·6 to 1·3° C. warmer than the lower stratum. Such a contrast between the two strata so late in the year is probably due partly to the existence of different currents in the two strata; either there is a southward movement at the surface, or the northward movement is strongest in the cold stratum.

Large temperature differences between the two strata have been noted most frequently in the region between the Falkland Islands and South Georgia. They appear to be caused by a movement of sub-Antarctic water towards the south or east; the movement does not terminate abruptly where the bulk of the Antarctic water sinks but carries a surface stratum of sub-Antarctic water 100–200 miles[1] farther south. At St. 1027 in section 3 (Plate IV) the average temperature of the first 50 m. of water was 3·53° C. as early as the middle of November, but that of the water between 100 and 200 m. was only 0·68° C. Similar differences were found at Sts. 634, 635, and WS 519 (Station List, 1932) in the same region. The difference between the surface and the cold strata appears to be increased in the same way at Sts. 1053 and 1054 (section 4, Plate VI), north of South Georgia, but the smaller temperature differences, 1·4 to 2·2° C., indicate that the sub-Antarctic water is mixed to a greater extent with Antarctic water. Large differences between the two strata have also been noted near the convergence in 23° W. The evidence of the southward movement at the surface and the factors which are likely to give rise to it will be discussed further in the following section of the report.

---

[1] Throughout the report distances are expressed in nautical miles.

In the regions where there is a current difference between the two strata the Antarctic layer may not become homogeneous in winter; and the difference found between the two strata south of Australia, for example, may persist throughout the winter. There are not, however, sufficient data to show definitely that it does. In the Falkland Sector, where observations have been made in the coldest month—that of August—the layer has been found to be uniform to within at least a short distance of the convergence. Between the Falkland Islands and South Georgia, where a current difference between the two strata is to be most expected, the temperature difference at St. WS 254 (Station List, 1930), was only 0·11° C, and recent observations during the same month at St. 1390 in 22° 15′ W show that there the layer was uniform. The existence of a southward movement which will give rise to a temperature difference between the two strata appears, however, to be more likely in winter than in summer (see p. 37), and the absence of strong indications of it in the Falkland Sector is evidence that the great vertical mixing in winter produces a uniform water column in spite of the current difference.

The contrast between the surface stratum and the rest of the layer seems to be increased in certain other localities by the meeting of different Antarctic currents. At Sts. 1029–30 (section 3, Plate IV), just north of the boundary between the Weddell Sea and Bellingshausen Sea currents in the Falkland Sector, the surface water was 1·35 and 1·38° C. warmer than the cold stratum. Such a large difference, found as early as the middle of November, cannot be due solely to the warming of the surface stratum of a homogeneous water mass, but must be caused partly by the sinking of the colder heavier Weddell Sea water below the lighter warmer Bellingshausen Sea water. At Sts. 1031–3, where the Antarctic layer probably contains only Weddell Sea water, the temperature difference between the two strata was only 0·61 to 0·50° C. A large difference between the two strata is to be expected wherever the main drift of Antarctic water towards the north-east is joined by a surface current which flows more directly northwards, as in the region east of the Kerguelen-Gaussberg ridge, north-west of the Balleny Islands, and north-east of the Ross Sea (see pp. 31 *et seq.*).

The nature of the surface stratum in summer is notably influenced by the presence of melting ice. The changes are illustrated by the observations in section 5 (Plates VII, IX) which, south of 60° S, were all made in narrow lanes through pack-ice. The water in the cold stratum was found to have almost the same properties as it would have in winter. An approximate estimation based on the observations made by Brennecke (1921, pp. 154 *et seq.*) indicates that in winter the Antarctic layer is uniform down to a depth of 80–150 m. with a temperature of – 1·8 to – 1·9° C. and a salinity of 34·4 to 34·5 °/₀₀. Our observations made in January show that the cold stratum still had a temperature of – 1·52 to – 1·86° C. and a salinity of 34·34 to 34·50 °/₀₀.

At the surface, however, the conditions in summer are very different from those of winter, though the changes are confined for the most part to a very shallow stratum, which has a very low salinity and a temperature 0·3 to 0·6° C. higher than that of the cold stratum. South of 60° S in section 5 the salinity of the surface water varied from 32·82 to 33·82 °/₀₀, and the temperature from – 0·76 to – 1·55° C. The observations at St. 816 show how shallow a stratum is affected. The salinity of the water down to a depth of 10 m. was only 33·25 °/₀₀, whilst that of the water at 20 m. was as much as 34·33 °/₀₀. An examination of all the data south of 60° S in the section shows that the water at a depth of 40 m. had in the summer an average salinity only 0·1 °/₀₀ below that of the water in the cold stratum, but between 10 and 40 m. the average difference was about 0·8 °/₀₀.

A similar sharply defined surface stratum is nearly always found in summer near the Antarctic Continent and Antarctic islands situated in high latitudes. In such regions there is usually an abundant supply of fresh water, which because of its low density floats above the colder highly saline water in a shallow stratum. The winds in the high latitudes are also generally less strong than those farther north, and the surface water is often protected to some extent from even their relatively small disturbing influence by a covering of drift-ice. Farther north, where the winds are stronger and the seas less sheltered, the poorly saline water is more evenly distributed through a deeper stratum. Owing to their stability the poorly saline strata do not readily pass on to the deeper water the heat which they receive as radiation from the sun; on the contrary, their rising temperature increases their stability and prevents vertical mixing. The continuous records of the temperature at a depth of 2–3 m., obtained while cruising in high latitudes in summer, show that the water close to drifting ice may be as much as 4° C. warmer than the water some distance away from it. Such large differences have, however, only been found on very calm sunny days, and their absence on the succeeding stormy days shows that they are only short-lived.

## THE MOVEMENTS OF ANTARCTIC SURFACE WATER

The principal movements of the Antarctic surface water are towards the east in latitudes north of 65° S, towards the west farther south, and a general northward movement, stronger in some meridians than in others, throughout the whole of the zone. The movements have two chief causes; the eastward and westward currents appear to be caused primarily by the effect of the prevailing winds, but the northward movement, though partly the effect of the wind, seems to be due mainly to the influence of the cold Antarctic climate on the density distribution.

The action of the winds on the sea cannot be examined very closely, but their influence on the surface water is fairly well known and there are some indications as to what happens in the deep water. Ekman (1928) has shown that in a homogeneous sea the combined effect of the wind, the earth's rotation and friction, will give rise to a relatively shallow-reaching current which he has called a pure drift current. In the southern hemisphere the surface water in this current flows in a direction 45° to the left of the wind; below the surface the current turns more and more towards the left and its velocity decreases until at a depth which has been called the "depth of the wind's frictional influence" the velocity is negligibly small and directed opposite to the surface current. Between the surface and this depth, which in the Southern Ocean is probably not more than 60–100 m., the total transport of water is directed 90° to the left of the wind.

These conclusions are in approximate agreement with the facts as far as they are known at present; the angle of 45° between the wind and the current, an important part of the theory, has frequently been confirmed. The theory further states, however, that the action of the pure drift current in piling up water to the left of the wind against a coast or another water mass will give rise to a deep current in the direction of the wind, and this current, called by Ekman a slope or gradient current, influences the greater part of the water column in the ocean; between the relatively thin surface and bottom layers which are influenced by friction with the wind and the sea-floor, it flows with uniform velocity.

Where such a deep current exists the actual movement at the surface is the resultant of the pure drift current and the deep current, and it will therefore be directed at an angle less than 45° from the wind; the total transport within the depth of the wind's frictional influence will also be made to have a component in the direction of the wind. The more recent work of Ekman suggests, however, that under the actual conditions found in the sea the part played by the deep current is not likely to be as comprehensive as was first supposed. In regions where the wind is not constant, where the depth of the sea varies, or where the deep current flows from one latitude to another, the current will be modified by mixing and eddy movements. Thorade (1933), in a note on Ekman's most recent paper (1932) and the development of the theory, mentions that the frequent confirmation of the angle of 45° between the wind and current gives some indication that the drift current generally exists without the deep current. In the Southern Ocean Krümmel (1911, II, pp. 680–1) shows that there is poor agreement between the theoretical wind currents and the observed currents, but the angle between the surface current and the wind cannot be regarded as a reliable indication of the deep water movements owing to the existence of a northward movement caused by other factors.

The density distribution points to the existence of a strong deep current; the surfaces of equal density and specific volume (isosteres) slope downwards to the north and the isobaric surfaces in the opposite direction, towards the south. According to Ekman the first effect of the wind on a non-homogeneous sea is to set up a pure drift current which transports the light surface water to the left of the wind, and where this movement is restricted by a long straight coast or another water mass which belongs to a different current system it will give rise to such density and pressure distributions, and to a deep current, which he has called a convection current, in the direction of the wind.

This current must to a large extent replace the slope current of the homogeneous sea. An attempt to decide whether the actual piling up of the water on the left of the wind is greater than that indicated by the density distribution has been made by Sverdrup (1933), but he was forced by a lack of information to leave the question unsolved. He points, however, to some observations from the Strait of Florida and the Newfoundland region which indicate that the deep current is completely accounted for by the density distribution.

In the Southern Ocean the density distribution appears even to exaggerate the strength of the deep current, and a close examination of the data illustrated in the vertical sections across the ocean (Plates I–XLIII) shows that the slope of the layers is partly due to the existence of continuous movements of Antarctic water sinking towards the north, and of warm deep water climbing towards the south. The problem has so far not been investigated quantitatively, but there is little doubt that the eastward movement is not as strong as the slope of the surfaces of equal density would at first suggest.

These considerations, as far as they affect the Antarctic surface water, show that the west wind will cause the surface water to flow east and north, and the total transport within the limit of the wind's frictional influence, probably about 60–100 m., will be more northerly than the surface current. The movement will be modified where the depth of the sea varies, in the neighbourhood of land and submarine ridges.

The northward movement of Antarctic water appears to be due partly to another cause—a density gradient maintained by differences of climate. Since the cold Antarctic water is heavier than the warmer surface waters found farther north thermodynamical considerations demand that it should sink and be replaced by a southward movement at the surface, and the northward movement of the Antarctic water in both the surface and bottom layers may be largely the result of such density differences.

The Antarctic bottom water is the heaviest type of water formed in the Antarctic regions. It starts as highly saline water cooled to freezing-point on the wide continental shelf south-west of the Weddell Sea, and sinking down the continental slope it mixes with the warmer water of the deep layer and flows away towards the north and east as a bottom current. The earliest theories of oceanic circulation maintained that it climbed to the surface in the equatorial regions and was returned southwards as a surface current, but it is now known that the circulation is not so simple.

Salinity differences between regions of great and little evaporation give rise to other heavy and light waters; the prevailing wind systems govern the movements of the various waters to some extent and form cyclonic and anticyclonic systems in which they upwell or sink, and the movements in the surface, deep, and bottom layers are also dependent on the disposition of the land masses and submarine ridges. Such factors explain the modern scheme of circulation devised by Merz and Wüst (1922) partly illustrated in Fig. 1. The presence, for example, of a shallow submarine ridge across the Davis Strait, and between Greenland and the north of Scotland through Iceland and the Faeroe Islands, largely prevents the entry into the Atlantic Ocean of an Arctic bottom current similar to the Antarctic current, but another combination of circumstances, mainly perhaps the strong anticyclonic wind and current systems and the high evaporation in the subtropical part of the North Atlantic Ocean, lead to the sinking of the highly saline North Atlantic deep current which enters the South Atlantic Ocean above the Antarctic bottom current. The thermodynamical compensation for the bottom current is probably effected by this southward movement of North Atlantic deep water into the Antarctic regions instead of by a southward movement at the surface.

The Antarctic surface water is a mixture of fresh water from melting ice and snow with highly saline water from a warm deep current such as the North Atlantic deep current, and its properties are modified while it is exposed at the surface by freezing in winter and thawing in summer. It has a low temperature, which makes it heavier than the surface waters farther north, but owing to its low salinity it is lighter than the highly saline warm deep water. Vertical sections through the region of westerly winds show that it lies above the warm deep water in a layer whose thickness increases gradually from about 80 m. in the south to 250 m. in the north; the heaviest water with the lowest temperature and highest salinity lies at the southern end of the sections, and the isosteric surfaces slope gradually downwards to the north. Such a slope of these surfaces may, as described above, be partly due to the influence of the west wind, but it cannot be overlooked that the greater amount of radiation falling on the northern part of the region compared with the southern part will lead to a density distribution with the same features.

Although the density gradient arising from the differences of climate will tend to make the Antarctic water sink and be replaced by a southward movement at the surface, the Antarctic surface water cannot sink vertically like the Antarctic bottom water because it is not heavy enough to force its way through the highly saline warm deep layer. It can, however, find its way gradually to a deeper level by spreading northwards in the lower part of the surface layer, and farther north, where the warm deep layer rises abruptly towards the south, it is free to sink more steeply.

In the absence of a wind from the west the sinking of the Antarctic water to the lower part of the layer in the southern part of the zone would tend to set up a southward current at the surface; there are some indications that such a movement may exist in certain regions (see pp. 8, 36, 37), but generally the current appears to be directed towards the north, the influence of the wind seeming usually to predominate. The combined effects of the wind and thermohaline differences may therefore be supposed to lead to a northward movement in both the upper and lower strata of the surface layer. In summer the northward movement will be assisted by the addition of thaw-water to the layer from melting ice and snow, water which was originally deposited on the sea and neighbouring land in the form of precipitation, or removed from the sea during the winter as sea ice.

South of 65° S the prevailing east wind will set up a drift current which carries the surface water to the west and south. In winter it will be assisted by the sinking of cold heavy surface water in the neighbourhood of the continent. In the Weddell Sea part of the water whose density is increased by the freezing processes is made heavy enough to sink below the warm deep layer to give rise to the Antarctic bottom current, but generally it finds its way northwards in the lower stratum of the surface layer. In summer the southward movement at the surface is likely to be hindered by the liberation of fresh water from melting ice and snow which will restrict the southward movement of the drift current by the formation of an opposing solenoid field. Assuming the winds to be the same in both seasons, the effect of the low winter temperatures will be to bind the Antarctic pack-ice closely round the continent, whilst the warmer climate in summer will facilitate its dispersion towards the north.

## THE EAST WIND DRIFT

Since there is very little doubt that the drift towards the west along the coast of the Antarctic Continent is primarily the result of the prevailing east wind it is probably best referred to as the East Wind Drift. Like the West Wind Drift farther north it is practically a circumpolar current.

It is only interrupted in the south-west corner of the Atlantic Ocean where its path is obstructed by Graham Land, Trinity Peninsula, and by the adjoining South Shetland Group. There is, however, a small current towards the west round the northern extremity of Trinity Peninsula, where a stream of cold water which has its origin in the Weddell Sea flows westwards into the Bransfield Strait (Clowes, 1934, p. 62). A summary of the wind observations north-east of Trinity Peninsula made by Mossman (Antarctic Pilot, pp. 73–4) shows that winds from the south and east are more frequent than those from the north and west. The movement of Weddell Sea water westwards into the Bransfield Strait is evidently partly due to the greater prevalence of south-east winds, but it may also be caused by an accumulation of water from the circumpolar westward movement, in the north-west corner of the Weddell Sea, or it may be a counter-current to the great eastward movement through the Drake Passage. It appears to be only a weak current, flowing a short distance down the southern side of the Bransfield Strait and forming an eddy with water flowing in the opposite direction.

Farther south, in the neighbourhood of the Palmer Archipelago, there appears to be a break in the westward movement. In the De Gerlache Strait between Brabant and Anvers Islands and the mainland the current flows towards the north-east (Antarctic Pilot, 1930, p. 84). The high salinity of the surface water at Sts. 1002 and 1003 (section 19, Plate XLIII) on the continental shelf north-west of the islands is evidence that a current towards the north-east is causing the water to upwell there.

The information from the west coast of Graham Land south of the Palmer Archipelago indicates that the westerly current is soon regenerated. A winter's observations at Petermann Island showed that winds from the north-north-east and north-east predominated and were always strong, whilst winds from the south-south-west and south-west were much less frequent and blew less strongly (Rouch, 1911, p. 182). The prevailing wind should therefore give rise to a movement to the south-west along the coast and also to an onshore current.

The existence of such currents is confirmed by an examination of the density distribution at right angles to the coast. Fig. 2 shows the density distribution along a line north-west of Adelaide Island, based on the observations made at Sts. WS 509–17 in February 1930 (Station List, 1932). The slope of the surfaces of equal density downwards to the south-east shows that there is a current along the coast towards the south-west, as well as an onshore movement which keeps the light surface water piled up against the coast. Fig. 3 shows a similar section made in January in the following year. In this section the surfaces of equal density show practically no slope towards the coast, whilst north of St. 589, 100 miles offshore, they slope definitely to the north-west. When these observations were made there can have been very little movement towards the south-west or towards the coast, and 100 miles offshore there is evident indication of a current towards the north-east.

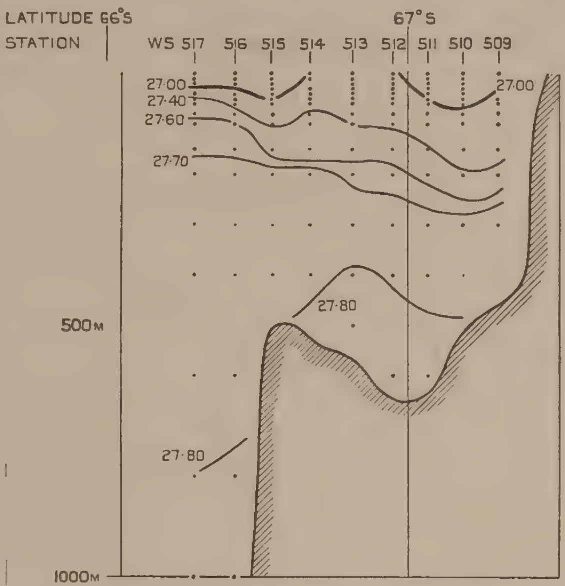


Fig. 2. The vertical distribution of density ($\sigma t$) along a line north-west of Adelaide Island, February 1930.

Very little information on the water movements off the west coast of Graham Land has been obtained by actual current observations. The 'Pourquoi Pas?' experienced a

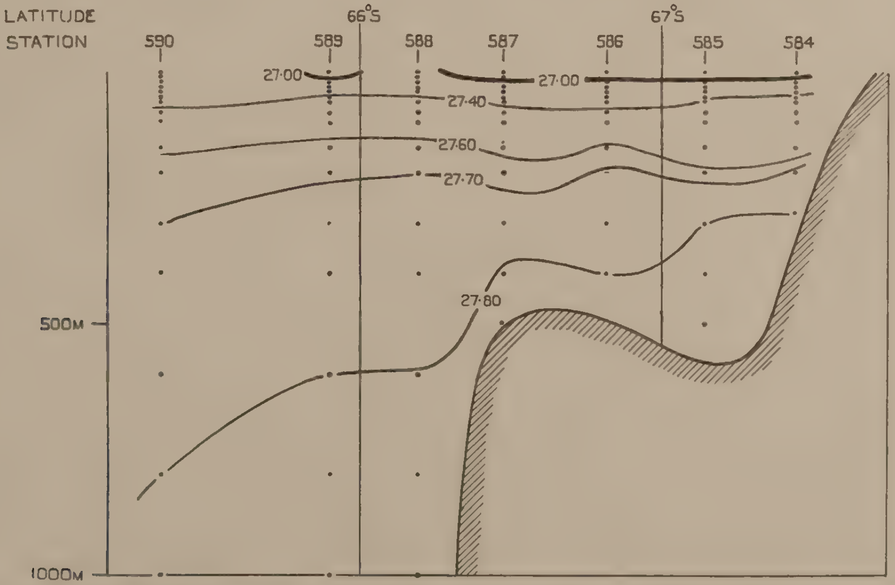


Fig. 3. The vertical distribution of density ($\sigma t$) along a line north-west of Adelaide Island, January 1931.

southerly set near Adelaide Island and Alexander Ist Island, but a northward movement was observed in Matha Bay and Marguerite Bay (Bongrain, 1914, p. 6). The French ship in 1908–10 and the 'William Scoresby' and 'Discovery II' in 1930–1 each found that south of the Palmer Archipelago icebergs were much more numerous than in the neighbourhood of the South Shetland Islands. This concentration may be partly caused by the north-easterly current from the Bellingshausen Sea turning towards the coast and back to the south-west.

The sea between Adelaide Island and Charcot Island has generally been found closely packed with ice, and this may be an indication that the surface water is piled up towards the coast, as it would be on the left flank of a current towards the south-west. The density distribution in the surface water, illustrated by Rouch (1913, pl. ii), also points to this conclusion. The evidence as a whole suggests that the movement towards the west is generally restored south of the Palmer Archipelago, but indicates that its strength may vary considerably.

The drift of the 'Belgica' when beset in the ice showed that although the water movements in the southern part of the Bellingshausen Sea were very variable, the resultant current was towards the west. The 'Belgica' drifted from 71° 30′ S, 85° 15′ W to 70° 50′ S, 102° 15′ W, between February 1898 and March 1899, but except during the last two months, when she drifted rapidly westwards, she moved backwards and forwards over the same ground. The total length of the drift was 1706 miles, but the resultant movement towards the west only 333 miles (Wordie, 1921). The average rate of the drift towards the west was only 0·9 mile a day, but during the last two months 4–5 miles a day. The meteorological observations made during the drift showed there were more westerly winds in winter but more easterly winds in summer.

The downward slope of the isotherms and isohalines towards the south gives a further indication of the existence of a coastal current towards the west. The temperature and salinity distribution in 80° W (section 18, Plate XLI) suggests that the northern boundary of the current lies in 68–69° S. The position is, however, not very certain, because the observations in the westerly current were made in summer, and those in the easterly current in winter. In winter the boundary is probably farther south: the observations made by the 'Belgica' (Arctowski and Mill, 1908) show signs of a divergence region south of 70° S; in summer it is probably farther north.

The observations made in sections 16 and 17 (Plates XXXVII–XL) show that between 98 and 105° W a movement of the surface water to the east is found as far south as 70° S. A comparison of the sections with section 18 indicates that the easterly current extends farther south to the west of Peter Ist Island than it does to the east. In the neighbourhood of the island itself (68° 49′ S, 90° 32′ W) the surface water has been found to flow northwards. The 'Pourquoi Pas?' found a northward current carrying a large number of icebergs (Bongrain, 1914, p. 6), and a northerly set was also experienced by the 'Odd I' (Antarctic Pilot, 1930, p. 89).

The evidence of a greater current towards the west in longitudes east of Peter Ist Island and of a northward movement near the island itself suggests that the westerly current is to some extent deflected northwards near the island, probably owing to the influence of a submarine ridge. This conclusion implies that the surface waters south of the Antarctic Circle in the Bellingshausen Sea have a tendency to circulate in a clockwise direction.

Although in the region west of Peter Ist Island the westerly current is only found south of 70° S, it expands to a much greater range north of the Ross Sea. The temperature and salinity distributions in section 14, Plates XXXI–XXXIII, suggest that in 165° W the boundary between the westerly and easterly currents lies in 65–68° S. The observations made at the Ross Sea stations 4–24 (Station List, 1930) show no sign of the boundary between the two currents south of 64° S in 171° E, and current observations in the approach to the Ross Sea show that the current usually sets to the westward south of 62° S (Antarctic Pilot, 1930, p. 153). Farther west between 153 and 160° E the observations in sections 12 and 13 (Plates XXV–XXX) show that the isotherms and isohalines slope upwards to the south as far as 61–62° S, indicating that the current boundary lies farther south.

In the Ross Sea itself the current sets westward along the barrier at about one to three knots, and northward along the western shore (*ibid.*). The path taken by the water flowing out of the sea is shown plainly by the drift of the 'Aurora' in 1915–16. The track of the drift makes a grand sweep along the coast of Victoria Land, round Cape Adare, between the Balleny Islands and Oates Land, and away to the north-west. North of 65° 30′ S the direction of the drift changed to the north-east, indicating that the region of westerly winds began just north of this latitude (Wordie, 1921). The average rate of the drift in the principal direction of movement was 2·8 miles per day (*ibid.*).

Farther west the current has been observed north of King George V Land and Adelie Land. There is little doubt that it also exists along the whole of the Antarctic coast south of Australia, but it must be confined to a very narrow coastal region: the observations in sections 10 and 11, Plates XIX–XXIV, show that in 130° E the easterly current extends as far south as St. 887, within 150 miles of the land.

The observations made by Drygalski in the 'Gauss' show that between 80 and 90° E the westerly current is again restricted to a narrow coastal strip and does not extend north of 65° S (Willimzik, 1924, p. 27). In the neighbourhood of the coast, between 60 and 70° E, the 'Discovery' experienced a westerly set of 12–13 miles a day. The current has also been observed along the coasts of Kemp and Enderby Lands; in summer it has a speed of about 7 miles a day (Antarctic Pilot, 1930, p. 134). The observations in section 8, Plates XIII–XV, suggest that north of Enderby Land the northern boundary of the current lies near St. 854 in 63° 30′ S, 46° 25′ E. The observations in section 7, Plates X–XII, though too far apart to give precise information, show that south of Cape Town the boundary may lie as much as 3 or 4° farther north.

In the eastern half of the Atlantic Ocean the surface water has a low temperature near the continent, and also north of 60–65° S in a region where the easterly current carries cold water from the northern side of the Weddell Sea. In the intervening region the higher temperature of the water (see Fig. 8, p. 29) suggests that the principal movement is towards the south-west, but the observations in this part of the ocean show that the boundary between the easterly and westerly currents is not so well defined as it is in the Indian Ocean: the easterly current is well marked north of 60–65° S and the westerly current near the continent, but the intermediate region, although proved by the upwelling of the deep water to be a divergence region, appears also to be one of irregular movements.

The observations in section 6, Plates VIII and IX, and in a section drawn by Mosby from the 'Meteor' and 'Norvegia' data (Mosby, 1934, Figs. 17–19), between 10° W and 10° E point to the existence of a divergence region in 61–66° S. In 15–20° W the observations made at Sts. WS 552–5 (Station List, 1932) indicate a sharper divergence between 64 and 68° S. The data in section 5, Plates VII and IX, show that in 22–23° W there is an ill-defined divergence region between 64 and 70° S. The longitudinal section made by Brennecke through the Weddell Sea (1921, pl. 4–9) shows that there is a divergence region in 62–70° S; the observations are, however, so far apart that they probably miss such irregularities in the temperature and salinity distribution as are shown in section 5.

Along the western shores of the Weddell Sea the westward-flowing water turns northward; a good indication of the path that it takes is given by the drifts of the 'Endurance' and the 'Deutschland'. The 'Endurance' drifted first to the west between 76 and 77° S, then north-west as far as 74° S, and farther north the drift of the ship and later of the ice-camp was north-north-west or north. The 'Deutschland', beset 100–150 miles farther from the coast, drifted north-west as far as 72° S, northwards between 72 and 66° S, and then north-east.

The observations made during the drift of the 'Deutschland' show that the movement of the ice was caused only by the prevailing winds (Brennecke, 1921, p. 200), and they suggest that the bending of the westerly current towards the north off the east coast of Graham Land is entirely due to the existence of a prevailing northerly wind. A section was made across the northerly current by Nordenskjöld (1917, pl. 2). Within 200 miles of the coast the isotherms slope steeply towards the west, pointing to the existence of a strong movement towards the north; farther off-shore they are almost horizontal and indicate a lesser movement. As it flows northwards into the region of the westerly winds the current is turned towards the east; only a very small current turns round the northern end of Trinity Peninsula towards the west.

Summarizing, it will be noted that there are as yet few series of observations that can be used to fix the boundary between the easterly and westerly currents. In the neighbourhood of the boundary the surface currents will no doubt be irregular, and there is evidence of particularly wide zones of irregular movements north of the Weddell and Ross Seas. With the help of a large number of observations it would be possible to determine an average position, which itself would probably vary from winter to summer, as suggested by the observations made during the drift of the 'Belgica'.

The approximate position of the boundary as far as it is known at present is shown in Fig. 4. In the Atlantic and Indian Oceans the boundary is found in about 65° S, but

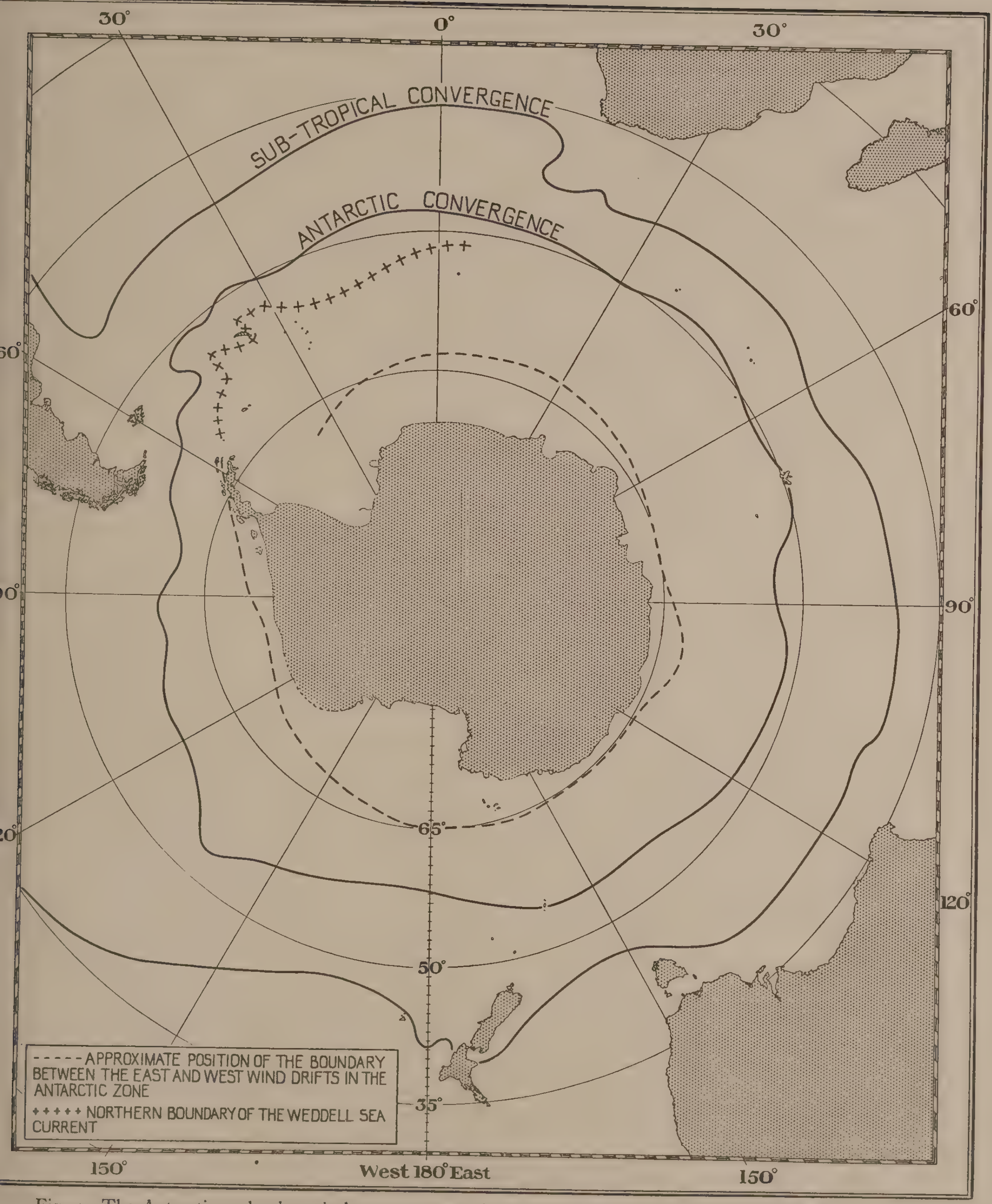

30°
0°
30°
SUB-TROPICAL CONVERGENCE
ANTARCTIC CONVERGENCE
60°
90°
120°
65°
50°
35°
150°
West 180° East
150°
- - - - - APPROXIMATE POSITION OF THE BOUNDARY BETWEEN THE EAST AND WEST WIND DRIFTS IN THE ANTARCTIC ZONE
+ + + + + NORTHERN BOUNDARY OF THE WEDDELL SEA CURRENT

Fig. 4. The Antarctic and subtropical convergences, the northern boundary of the Weddell Sea current, and the approximate position of the boundary between the East and West Wind Drifts.

between 90 and 120° W in the Pacific Ocean it lies in 70° S. The position suggests that the boundary between the east and west winds does not lie in 60° S as the available meteorological data has indicated (Antarctic Pilot, 1930, pp. iii, 7), but as much as 5–10° farther south. This is in closer agreement with the ideas of Mossman, who states that the boundary between the two winds is found in general near the Antarctic Circle (1918, p. 21).

There are very few observations that give any information about the north and south movements in the waters of the westerly current. The distribution of temperature, salinity, and oxygen content in the coastal region is in agreement with the conclusion, based on a consideration of the effect of wind and density differences, that there is a rotary tendency in the current: the surface water is carried southwards and the deeper water northwards.

The current observations made at the winter station of the 'Gauss' show that the easterly wind sets up a surface current towards the south, and a deeper movement along the coast towards the west-north-west (Drygalski, 1926, pp. 512–25). Drygalski considers that the outer margin of the drift-ice, described by most observers as being compact and only frayed out by certain winds for a limited time, is kept unbroken by the movement of surface water towards the south. He also affirms that because of the action of the surface current the belt of drift-ice substantially follows the coast, and from its position inferences may be drawn as to the position of the coast-line beyond it.

The formation of the light surface water, especially in summer, near the Antarctic Continent must, however, give rise to a northward movement from the region of the westerly current to that of the easterly current. The effect of projecting land, submarine ridges and ice-tongues will also lead to northerly movements which may carry water as far north as the region of westerly winds. The greatest movement of this nature is the northward current along the east coast of Graham Land; others caused by the effect of submarine ridges are found near the Kerguelen-Gaussberg ridge and the Shackleton ice-shelf in the Indian Ocean, and on a smaller scale near Peter Ist Island in the Pacific Ocean. The effect of projecting ice-tongues causing a smaller deflection to the north has been noted by Drygalski (1926, p. 513) and by Davis (1919, p. 158).

In the westerly current the northward movement is probably strongest in the lower stratum of the surface layer, but the northward movement of drifting ice frequently suggests that it also exists at the surface. The northward flow of water from the region of the westerly current to that of the easterly current near the Kerguelen-Gaussberg ridge and Peter Ist Island is marked by a northward extension of the ice-edge to the east of these localities.

## THE ANTARCTIC CONVERGENCE

South of 50° S, in the northern part of the Antarctic Zone, current observations are few and scattered, but combined with evidence obtained from an examination of the movements of drifting ice they show that the principal movement of the surface water is towards the east. The current is, however, directed not only to the east, but generally it has a northward component and occasionally one towards the south.

The eastward movement tends to carry the Antarctic water continuously round the whole of the Southern Ocean, but the northward movement, although it remains at the surface for a great distance, reaches in the end a latitude where it sinks suddenly from the surface to a deeper level. An examination of the temperature and salinity distribution in the sections that have been made across the Southern Ocean shows that the point at which the Antarctic current sinks is determined by the movements of the warm deep water and the Antarctic bottom water.

In the subtropical region the warm deep water flows southwards at a very great depth, below 2000 m. in 30–35° S, but on the threshold of the Antarctic region, where it meets a large volume of Antarctic bottom water flowing in the opposite direction, it climbs steeply towards the surface; in the Antarctic Zone it continues its way southwards just below the surface layer and usually extends to within 200 m., or less, of the surface. Its movements are illustrated by the diagram in Fig. 1 (p. 4), based on the temperature and salinity distribution in 30° W.

The vertical sections across the ocean show that where a large volume of Antarctic bottom water extends far north the upward movement of the warm deep water takes place far north, and at a steep angle, but where the bottom current is smaller the deep water climbs farther south and less steeply.

This conclusion is illustrated by the diagram in Fig. 5, which shows the temperature distribution in the Southern Ocean at a depth of 2500 m. At this depth the temperature decreases towards the south as the warm deep water climbs above the Antarctic bottom water; the decrease is gradual at first, but there is an abrupt fall of temperature where the warm deep water climbs most steeply and a further gradual decrease where the layers slope less steeply again farther south. The temperature measurements themselves are an approximate indication of the strength of the bottom current; they show that the most abrupt temperature changes, marking the places where the warm deep water climbs most steeply, are found where the low temperatures indicate that the bottom current is strongest.

A consideration of the circumstances shows that the warm deep water climbs towards the surface because it can only continue its southward movement above the Antarctic bottom water. The locality and the steepness of the upward movement must therefore be determined by factors which govern the flow of the bottom water. This conclusion is justified by observations which show that wherever the northward flow of the bottom water is influenced by the configuration of the sea-floor, the movements of the deep water are altered conformably.

The sudden upward movement of the deep water is discussed in this section of the report because it determines the latitude at which the Antarctic water sinks below the surface. Earlier in the report (p. 13) it was shown that the great density of the Antarctic water compared with the warmer surface waters farther north tends to set up a circulation in which the Antarctic water sinks and is replaced at the surface by a

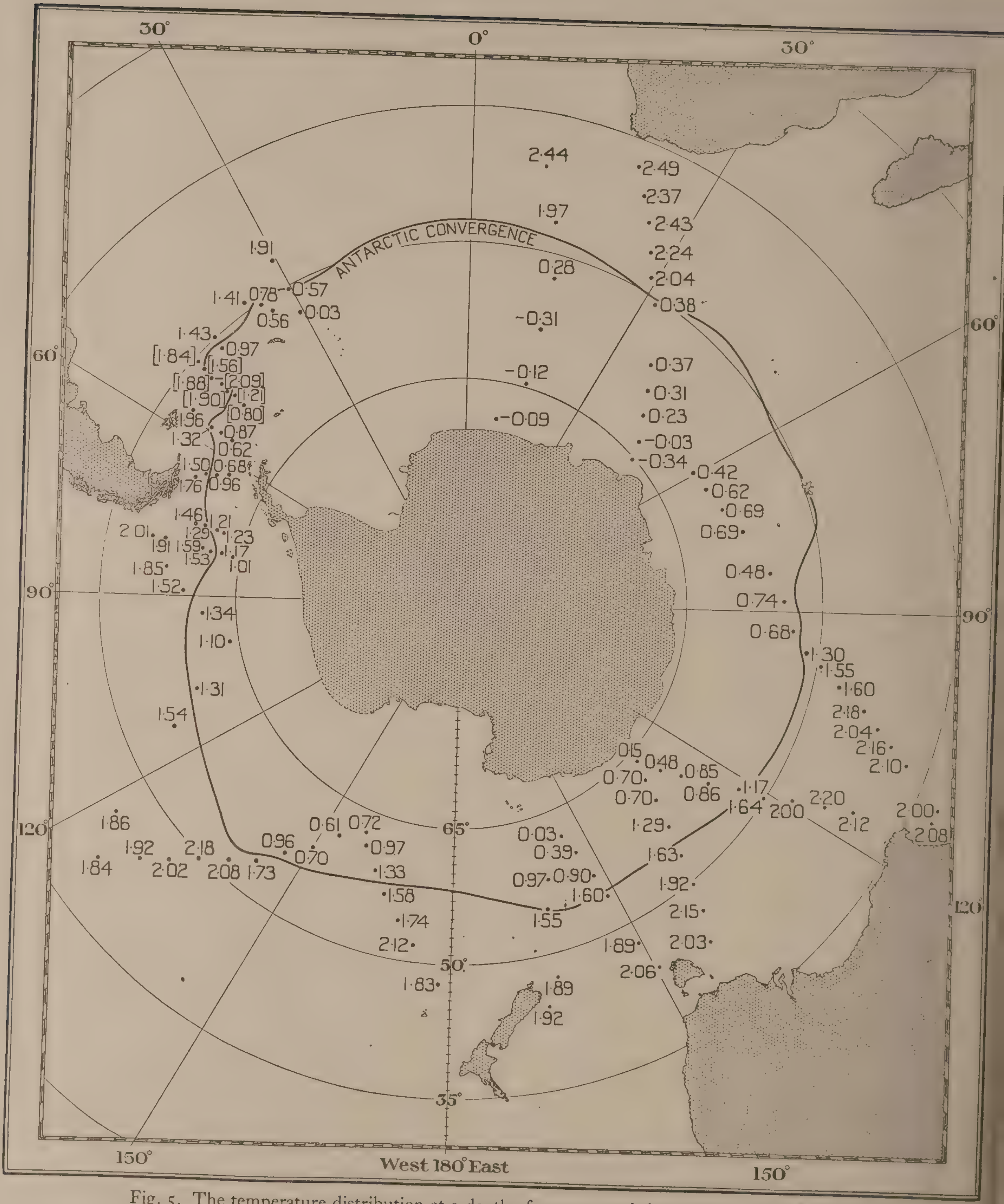

30°
0°
30°
60°
60°
90°
90°
120°
120°
150°
West 180° East
150°
65°
50°
35°
ANTARCTIC CONVERGENCE
2·44
2·49
2·37
2·43
2·24
2·04
0·38
1·97
0·28
-0·31
-0·12
-0·09
0·37
0·31
0·23
-0·03
-0·34
0·42
0·62
0·69
0·69
0·48
0·74
0·68
1·30
1·55
1·60
2·18
2·04
2·16
2·10
1·91
1·41
0·78
0·57
0·56
0·03
1·43
0·97
[1·84]
[1·56]
[1·88]
[2·09]
[1·90]
[1·21]
[0·80]
1·96
1·32
0·87
0·62
1·50
0·68
1·76
0·96
1·46
1·21
2·01
1·29
1·23
1·91
1·59
1·17
1·53
1·85
1·01
1·52
1·34
1·10
1·31
1·54
0·15
0·48
0·85
0·70
0·70
0·86
1·17
1·64
2·00
2·20
2·12
2·00
2·08
1·86
1·92
2·18
1·84
2·02
2·08
1·73
0·96
0·70
0·61
0·72
0·97
1·33
1·58
1·74
2·12
1·83
0·03
0·39
0·97
0·90
1·60
1·55
1·29
1·63
1·92
2·15
2·03
1·89
2·06
1·89
1·92

Fig. 5. The temperature distribution at a depth of 2500 m. and the position of the Antarctic convergence at the surface. The temperatures in brackets are for a depth of 2000 m.

southward current of warmer water. Actually, the Antarctic water is unable to sink vertically because it is borne up by the highly saline warm deep water which has an even greater density, but it gives rise to a northward movement just above the warm deep water. The surface water also flows northwards owing to the influence of the prevailing west wind, and thus, in the northern part of the zone, there is generally a northward movement in the whole of the Antarctic layer.

All the Antarctic water is heavier than the warm surface waters farther north, and although such a density distribution is stabilized to some extent by the wind, the water would sink if it were not prevented by the highly saline deep water. As soon, however, as the northward current has passed the point where the deep water climbs steeply towards the surface it is no longer prevented from sinking, and the sections suggest that the Antarctic water flows over the steep ascent of the warm deep water like a stream over a waterfall.

Where the Antarctic water has left the surface there is a sufficient depth of water above its new level to permit a movement of warmer sub-Antarctic water towards the south. Such a movement is known to exist, although not actually at the surface, and it brings the warm sub-Antarctic water into contact with the cold Antarctic water. Where the two waters meet there is generally a sharp boundary which at sea-level is known as the Antarctic convergence.

The surface water in the sub-Antarctic Zone generally has a northward movement which appears to be caused in a greater measure than the similar movement in the Antarctic Zone by the influence of the prevailing west wind. The existence of a sharp boundary at the surface, such as the Antarctic convergence, which is marked by a sudden change of surface temperature, implies, however, that there is a break between the northward currents in the two zones: the Antarctic current does not flow without interruption across the convergence and become a sub-Antarctic current, but sinks below the sub-Antarctic water.

Formerly I thought that a sharp convergence was formed because the Antarctic water flowed northwards more quickly than the sub-Antarctic water (1933, p. 187, and 1934, I, p. 129). A later suggestion by Sverdrup (1934, pp. 316–17) was that the effect of the wind on the sub-Antarctic water might be exceeded by the effect of the thermohaline differences, which tend to set up a southward movement. If, however, the convergence is formed because the northward current of Antarctic water sinks from the surface at a point determined by the deep water movements, a density difference between the two surface waters is all that is necessary to set up a sharp boundary. Where there is, for some reason, only a small difference between the densities of the Antarctic and sub-Antarctic waters a sharp convergence will not be expected.

The close agreement between the geographical position of the surface boundary and the zone of steepest ascent of the deep water is shown by Fig. 5, which gives, in addition to the temperature observations at a depth of 2500 m., the position of the Antarctic convergence determined from surface observations.

Since the latitude in which the deep water makes its sudden upward movement is determined by factors which govern the flow of the bottom water, it follows that the same factors fix the position of the Antarctic convergence.[1]

It will be shown in the following section of the report that although the position of the convergence is fixed primarily by the movements of the deep and bottom waters, it may be influenced within narrow limits by the surface currents themselves. In certain regions the water in the lower stratum of the Antarctic layer flows towards the north, and sinks at what would be the usual position of the Antarctic convergence, while the water at the surface flows in the opposite direction, towards the south. Owing to this movement sub-Antarctic water is carried southwards over the Antarctic water, and the convergence is found 100–150 miles to the south of its normal position.

Since the northward current of Antarctic water sinks as soon as it has passed the latitude where the deep water makes its sudden upward movement, it seems impossible that an increase in the strength of the current can affect the conditions at the surface to the north of this latitude and drive the convergence northwards.

According to the observations which have been made so far in the Falkland Sector, the position of the convergence does not vary much, probably not more than 60 miles between its extreme positions, and it shows no regular seasonal change. Such facts are in keeping with the conclusion that its position is fixed primarily by the movements of the deep and bottom waters, which are themselves only subject to minor variations.

Further information with regard to the movements of the Antarctic water in the neighbourhood of the convergence will be found in the following section of the report and in the section on sub-Antarctic water.

## THE WEST WIND DRIFT

In the Drake Passage the Antarctic water flows mainly towards the east. Along the line of section 1, between Elephant Island and the Falkland Islands, the boundary between the Antarctic and sub-Antarctic waters is very well defined. Between 55° 20′ S and 55° 10′ S the surface temperature increases from 1·5 to 5·5° C., and the isotherms and isohalines run almost vertically from the surface to a depth of 600 m. Such a sharp separation of the two waters suggests that their usual northward and southward movements are almost entirely restricted.

---

[1] Before arriving at this conclusion I searched for other possible explanations of the close agreement between the surface and deep observations. The agreement might lead conversely to the conclusion that the movements of the bottom water were determined in some way by those of the surface water, or it might suggest that both were regulated by some other factor which governed the movements of the deep water. Neither of these suggestions seems, however, to provide a possible explanation, and a closer examination of them helps to confirm the impression that the bottom water, being the heaviest water in the sea, has an overruling influence. The way in which the surface and deep currents accommodate themselves to the movements of the bottom water when these are determined by the bottom configuration supports this conclusion.

The sudden slope of the layers of surface, deep, and bottom waters in the neighbourhood of the convergence might also be due to the existence of a strong wind towards the east in this locality, with lesser winds to the north and south. There are, however, no such sharp changes in the strength of the wind, and as far as can be decided at present, no agreement between wind and slope.

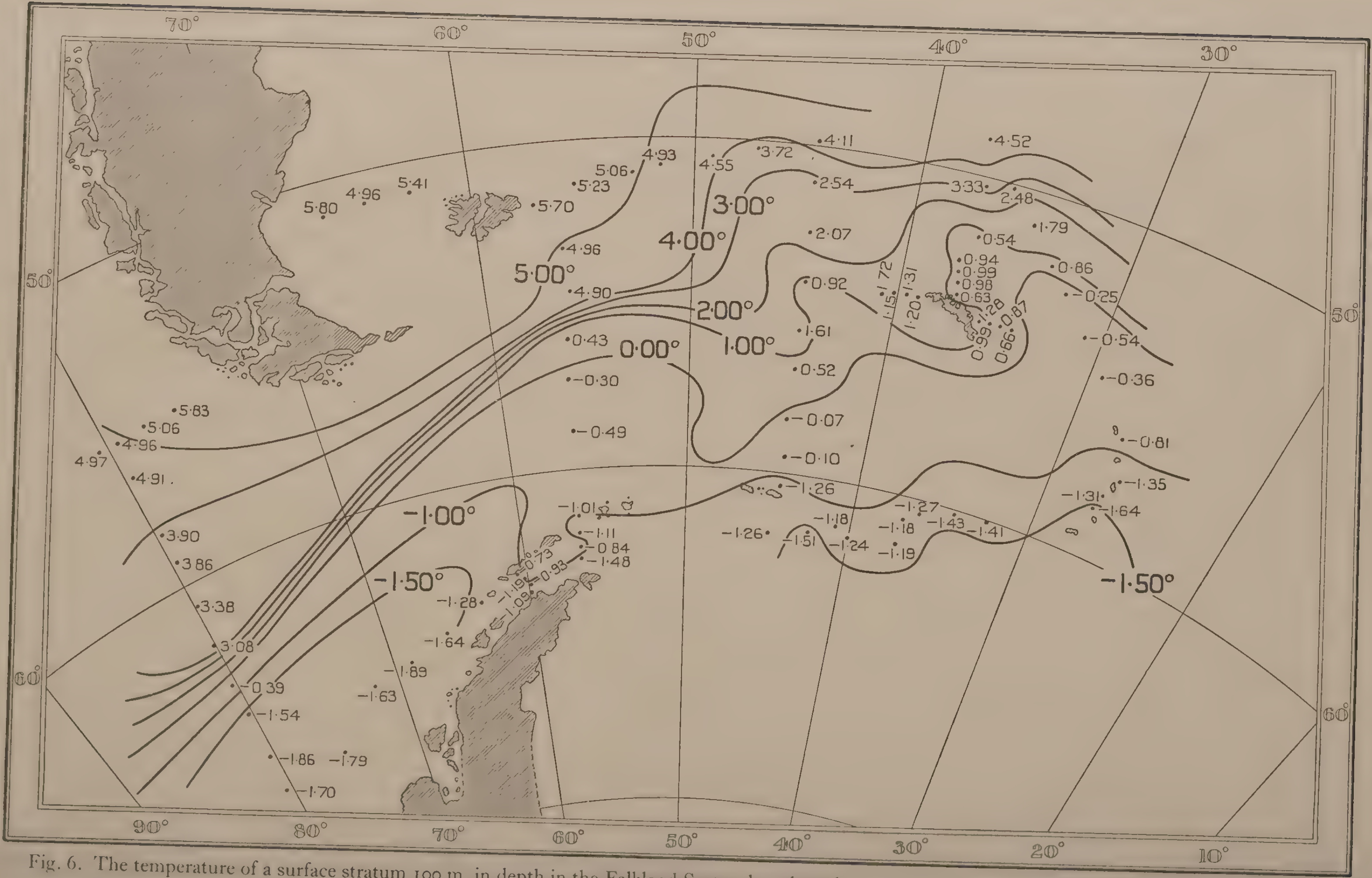
The strait is the only outlet towards the east for water which occupies a much wider zone in the Pacific Ocean. Antarctic water is deflected northwards west of Graham Land into the southern side of the strait, and sub-Antarctic water is deflected southwards west of Tierra-del-Fuego into the northern side. Such a large volume of water being forced through the strait will of itself cause a predominance of the lengthwise movement.

The distribution of temperature and salinity in the surface layer (Figs. 6 and 7) shows that on the southern side of the passage there is a current from the Bellingshausen Sea; at the end of winter it is made apparent by a stream of pack-ice which moves north-east, generally making the South Shetland Islands unapproachable until October or November. As it enters the Scotia Sea the current is joined by water which flows northwards out of the Weddell Sea, and vertical sections made across the two currents suggest that between them there is a convergence region in which the colder Weddell Sea water sinks below the lighter Bellingshausen Sea water.

Compared with the Antarctic convergence, that between the Weddell Sea and Bellingshausen Sea currents is only of secondary importance, and it does not give rise to such a well-marked boundary at the surface. In section 3 (Plate IV), the convergence is indicated by a rise in surface temperature of 1·5° C. between Sts. 1031 and 1030. Farther north, particularly at St. 1029, the cold stratum of the surface layer may contain a large proportion of Weddell Sea water, whilst the warm surface stratum belongs to the Bellingshausen Sea current. The low temperature and high oxygen content of the deep water at St. 1031 are evident indications of the existence of a convergence region in which the surface water sinks and mixes with the deep water, and the salinity distribution points to the same conclusion.

The temperature and salinity distribution in section 4 (Plate VI) show that there is a similar convergence region between the Weddell Sea and Bellingshausen Sea currents north-west of Zavodovski Island, the northernmost of the South Sandwich group. The convergence lies between Sts. 1051 and 1052; it is marked by an increase of 1° C. in the mean temperature of the first 100 m. of water, and by a small sinking of the isotherms and isohalines. The temperature distribution again suggests that Weddell Sea water sinks into the lower stratum, below a surface stratum of Bellingshausen Sea water.

East of the Scotia Sea, as far as the longitude of Bouvet Island, there are still signs of a convergence between the two currents. Section 5 in 22° W shows that there is a marked increase of temperature in 55° S between Sts. 804 and 801 (Plate VII) which probably indicates the position of the convergence. On a voyage from Cape Town to Bouvet Island in October 1930 the 'Discovery II' crossed the Antarctic convergence in 48° 35′ S; from this point as far as 51° 20′ S the surface temperature decreased gradually from 2·5 to 1·5° C., but during the next 60 miles it fell more rapidly to – 1° C. The first ice (a growler) was sighted in 51° 20′ S, and during the remainder of the voyage



70°
60°
50°
40°
30°
50°
60°
90°
80°
70°
60°
50°
40°
30°
20°
10°
5·00°
4·00°
3·00°
2·00°
1·00°
0·00°
−1·00°
−1·50°
−1·50°
5·80
4·96
5·41
5·70
5·06
5·23
4·93
4·55
3·72
4·11
4·52
2·54
3·33
2·48
1·79
2·07
4·96
4·90
0·43
−0·30
−0·49
0·54
0·94
0·99
0·98
0·63
0·86
−0·25
−0·54
−0·36
0·92
1·61
0·52
−0·07
−0·10
−0·81
1·72
1·15
1·31
1·20
1·28
0·99
0·66
0·87
5·83
5·06
4·96
4·97
4·91
3·90
3·86
3·38
3·08
−0·39
−1·54
−1·86
−1·79
−1·70
−1·63
−1·89
−1·64
−1·28
−1·19
−1·09
−0·73
−0·93
−1·01
−1·11
−0 84
−1·48
−1·26
−1·26
−1·18
−1·51
−1·24
−1·27
−1·18
−1·19
−1·43
−1·41
−1·31
−1·35
−1·64

Fig. 6. The temperature of a surface stratum 100 m. in depth in the Falkland Sector, based on the observations used in sections 1, 2, 3, 4*a*, 4, 18 and 19, and on other data collected at approximately the same time (October 25 to December 13, 1932).

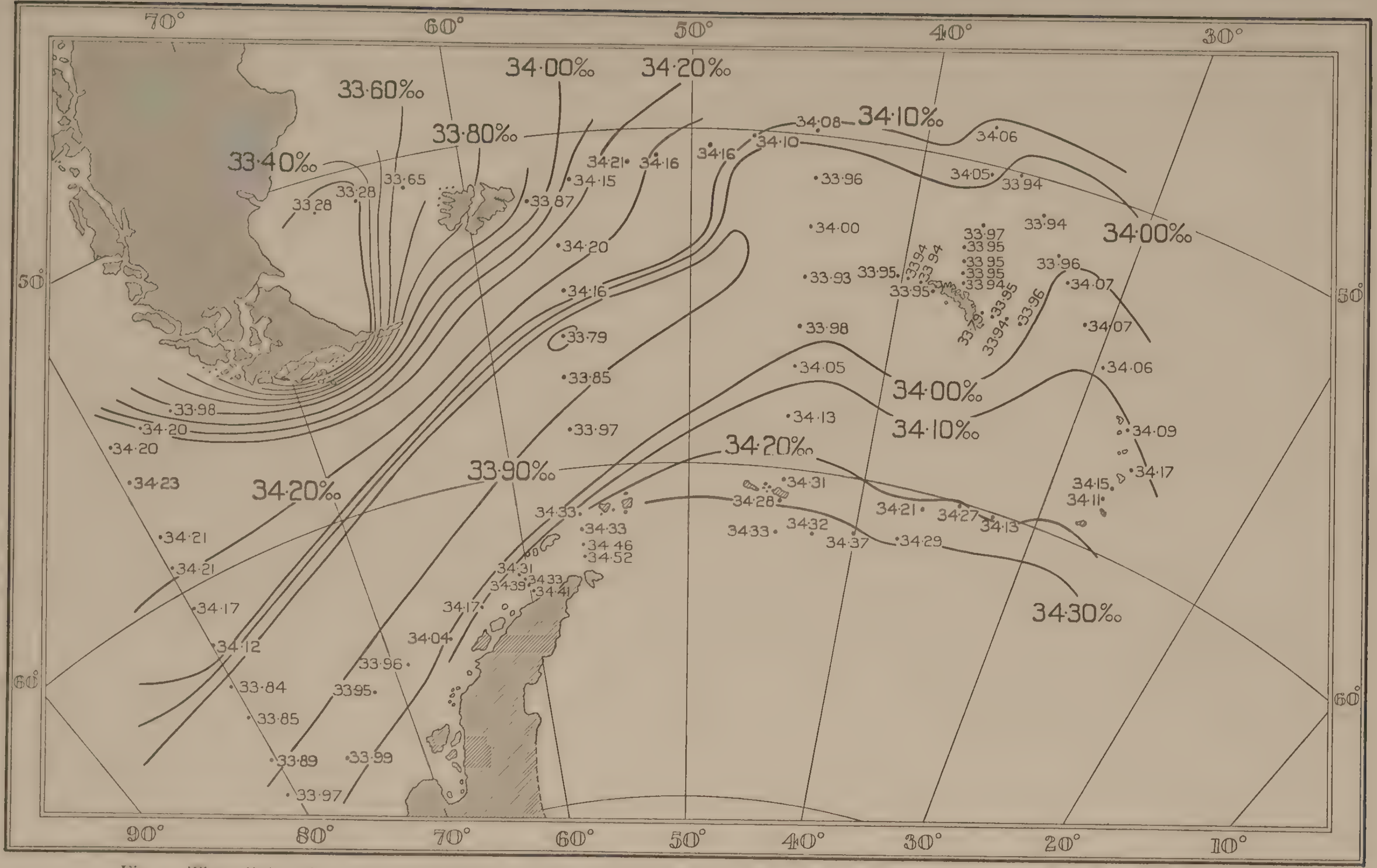

34·00‰
34·20‰
33·60‰
33·80‰
33·40‰
34·10‰
33·90‰
34·20‰
34·00‰
34·10‰
34·20‰
34·00‰
34·30‰
70°
60°
50°
40°
30°
90°
80°
70°
60°
50°
40°
30°
20°
10°
50°
60°
50°
60°
33·28
33·28
33·65
33·87
34·15
34·21
34·16
34·20
34·16
33·79
33·85
33·97
34·16
34·10
34·08
34·06
34·05
33·94
33·96
34·00
33·93
33·95
33·98
34·05
34·13
33·94
33·97
33·95
33·95
33·95
33·94
33·96
34·07
34·07
34·06
34·09
34·17
34·15
34·11
33·98
34·20
34·20
34·23
34·21
34·21
34·17
34·12
33·84
33·85
33·89
33·97
33·99
33·95
33·96
34·04
34·17
34·31
34·39
34·33
34·41
34·33
34·33
34·46
34·52
34·28
34·31
34·33
34·32
34·37
34·29
34·21
34·27
34·13

Fig. 7. The salinity of a surface stratum 100 m. in depth in the Falkland Sector, based on the same series of observations as Fig. 6.

ice was frequently encountered. The appearance of the drift-ice and the rapid fall in surface temperature both suggest that the water south of 51–52° S, within 200 miles of Bouvet Island, has a different origin from that farther north. Its properties, and the ice that it carries, suggest that it belongs to the Weddell Sea current, whilst the warmer water farther north contains the water from the Bellingshausen Sea and the Pacific Ocean. Another temperature record, made during a voyage towards the north in 14–15° E, showed that north of 55° S the surface temperature increased gradually, and there was no indication of a convergence south of the Antarctic convergence. The boundary between the Weddell Sea and Bellingshausen Sea currents, as far as it can be decided from the existing data, is shown in Fig. 4 (p. 19).

The coldest water in the Weddell Sea current is found 400–500 miles to the south of this northern boundary; the figures in Table I show its position in the lines of sections 5, 6, and 7.

Table I.

| Longitude | Latitude |
|---|---|
| 22–23° W | 61–64° S |
| 8–12° W | 61–62° S |
| 14–15° E | 55° S |

The cold water in the lower stratum of the surface layer at St. 850 in 50° 44′ S, 31° 44′ E (section 8, Plates XIII–XV) seems also to belong to the Weddell Sea current, but the surface temperature distribution, illustrated in Fig. 8, shows that as far east as this the current has almost lost its identity; farther east it can no longer be distinguished from the main body of the easterly drift.

Longitudinal sections east of 30° W show that between the Weddell Sea current and the well-defined westward movement near the continent, there is a tongue of warmer water. It is shown very clearly by the surface temperature chart in Fig. 8. The sections made across the region occupied by this warmer water show that it is an ill-defined divergence region and an area of irregular movements between the two opposite currents; the existence of the warm tongue of water is, however, reliable evidence of a predominant movement towards the west.

The movement towards the west, the northward current along the east coast of Graham Land, and the current flowing out of the Weddell Sea towards the east, form three parts of a cyclonic movement which extends across the entire width of the Atlantic Ocean. The surface temperature distribution indicates that the cyclonic movement may be completed by a southward movement between 20 and 40° E; there is, however, very little evidence of such a current at the surface; the conditions are not very different from those farther west and more in keeping with the existence of a small northward movement. The chart given by Fricker (1898), reproduced in Fig. 9, shows that the northernmost limit of pack-ice also bends towards the south in 30–40° E; the same can be seen to be true of the actual edge of the pack-ice in seasons when there are sufficient observations for it to be plotted (see a chart by Daehli, 1931). The curving of the pack-ice

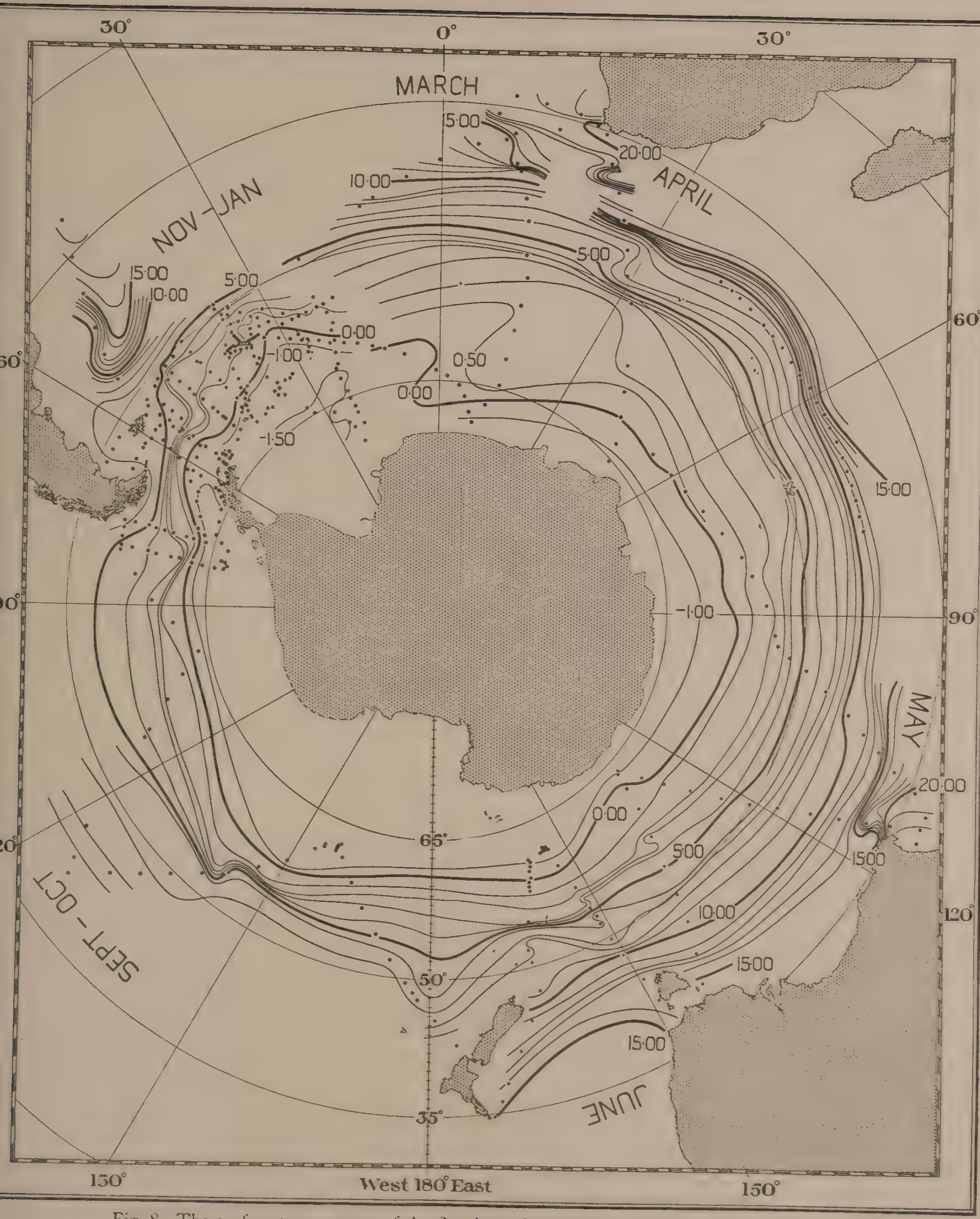

30°
0°
30°
MARCH
APRIL
NOV-JAN
15·00
20·00
10·00
5·00
0·00
-1·00
0·50
-1·50
60°
15·00
90°
-1·00
MAY
20·00
15·00
120°
0·00
65°
5·00
10·00
SEPT - OCT
50°
15·00
15·00
35°
JUNE
150°
West 180° East
150°

Fig. 8. The surface temperature of the Southern Ocean, November 1931 to March 1933.

boundary towards the south has been used by Michaelis (1923, p. 22) as evidence of a southward current, but it may be explained alternatively by the melting and disappearance of the ice carried eastwards across the Atlantic Ocean by the Weddell Sea current.

A consideration of the water movements in the eastern half of the Atlantic Ocean suggests that there are two belts of pack-ice: one between 55 and 65° S carried by the Weddell Sea current and another fringing the Antarctic Continent carried by the current towards the west. In the western part of the Indian Ocean the former ice-stream may have melted, leaving only the continental ice-fringe. It is just possible that even in winter there may be open water between the two ice-streams in the eastern part of the Atlantic Ocean.

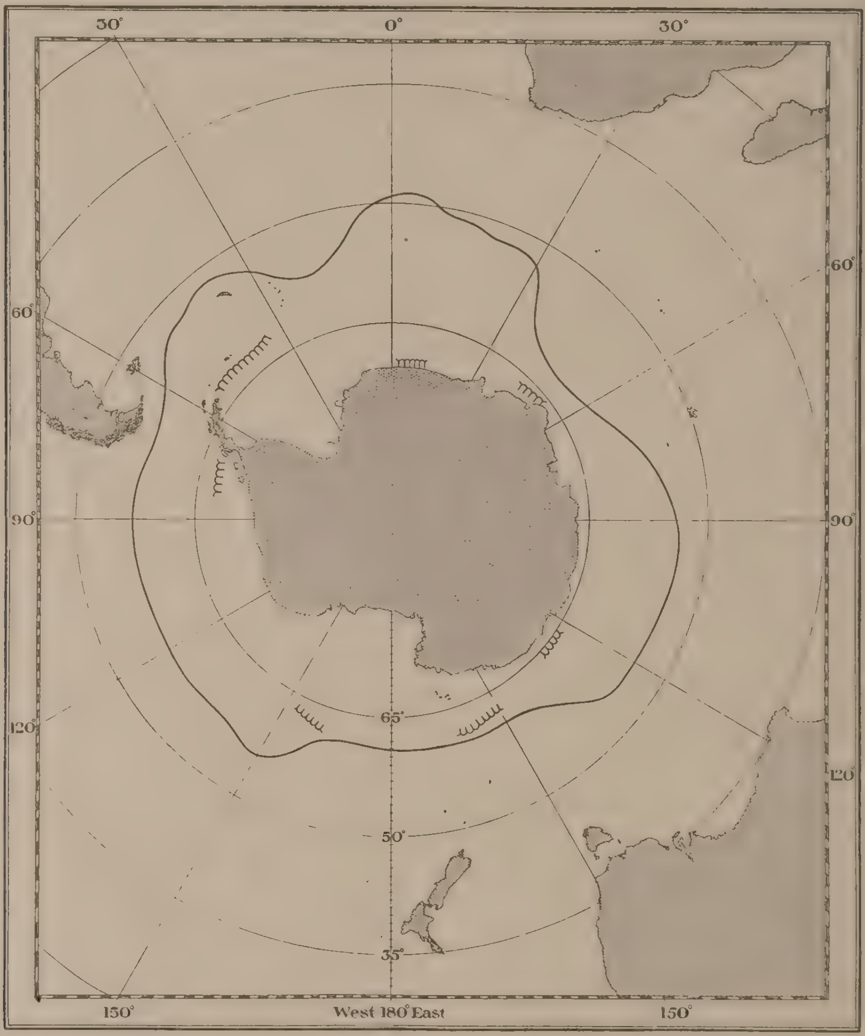


Fig. 9. The northernmost limit of pack-ice according to Fricker (1898) and the points at which the 'Discovery II' found the pack-ice between April 1932 and March 1933.

The low temperature of the surface water, and the occurrence of pack-ice so far north in the Atlantic Ocean, are largely the result of the transference of water from the East Wind Drift to the West Wind Drift by the northward current in the Weddell Sea. There are similar but smaller currents affecting the conditions at several other points round the Antarctic Continent in the same way. The distribution of temperature, salinity and oxygen content in section 9 (Plates XVI–XVIII) give evidence of such a current east of the Kerguelen-Gaussberg ridge. The movement appears to be greatest at St. 861, on the eastern slope of the ridge, and at St. 864, north of the Shackleton ice-shelf, where the bottom contours bordering the Antarctic Continent bend sharply northwards. The surface temperature distribution (Fig. 8) and the current chart drawn by Willimzik (1924, Abb. 1) both indicate a greater northward movement in this region; further confirmation is given by the ice chart (Fig. 9), which shows that pack-ice is found farther north. The bending of the edge of the pack-ice towards the north near the Shackleton ice-shelf in 1914 is shown by observations made by Davis in the 'Aurora' (1919, p. 152). The northward movement near the ridge and the ice-shelf is undoubtedly caused by the effect of the shallowing of the sea on the movements towards the east and west.

The surface temperature chart indicates that there are similar northward movements north-west of the Balleny Islands, north-east of the Ross Sea, and near Peter Ist Island. The first two currents are also indicated by the northward advance of the ice limits as given by Fricker (Fig. 9), and of the ice-edge as we found it, the first by a small advance near the Balleny Islands, and the second by a greater northward displacement north-east of the Ross Sea. The northward set near Peter Ist Island was experienced by the 'Pourquoi Pas?' and the 'Odd I' (see p. 16).

The indications of northward movement are particularly strong in the region north-east of the Ross Sea, and the idea of a current flowing out of the Ross Sea similar to the Weddell Sea current, at once presents itself. Part of the northward movement is, however, composed of the water which flows towards the east in the West Wind Drift. This drift is deflected northwards where it crosses the Cape Adare-Easter Island ridge (Plate XLIV), and until there are sufficient data to give a surface temperature chart of the approaches to the Ross Sea, the extent to which the northward current is joined by water from the sea itself cannot be determined.

Since Cape Adare lies well within the region of prevailing east winds, the greater part of the Ross Sea current flows round the cape towards the west. As it flows in this direction, the north-westerly trend of the coast-line, and the shallowing of the sea over a large coastal area between Oates Land and King George V Land, cause some of it to be deflected northwards. The bend of the isotherms and ice-boundaries towards the north near the Balleny Islands is probably caused by such a curving of the westerly current. The temperature and ice charts indicate that the northward movement is greatest in 150–160° E. It was in this region that the 'Aurora' was liberated.

When the water flowing northwards near the Balleny Islands reaches the region of prevailing west winds, it will be carried eastwards. Part of it will be deflected towards the north again near the Cape Adare-Easter Island ridge, and the data available at present suggest that only by this indirect route does the water flowing out of the Ross Sea reach the cold region north-east of the sea.

There are as yet insufficient data to show whether the Antarctic water that flows northwards near the Kerguelen-Gaussberg ridge and the Balleny Islands curves back to the south farther east and circulates in a clockwise direction. Such a possibility is indicated by the receding of the isotherms and ice-limits towards the south, but the changes may, on the other hand, be due only to a decrease in the strength of the northward movements. Of the currents which carry water into the northern part of the Antarctic Zone only the Weddell Sea current retains its individuality for any appreciable distance; the others merge with the main drift towards the east.

The path of the main drift in the northern part of the Antarctic Zone is indicated by the isotherms and isohalines in Figs. 6, 7, and 8. It does not flow due east but has northward and occasionally southward movements of varying strength. The width of the current and the extent of the Antarctic Zone are also subject to considerable variations; these are shown by the varying latitude of the Antarctic convergence in Fig. 4.

In the Scotia Sea the convergence bends north, north-west, and then back to the east. The north-westerly salient lies mainly to the north of the Scotia Arc (Herdman, 1932, p. 214), and it seems to exist principally because there is a greater flow of bottom water on that side of the arc: the warm deep water is forced to climb towards the surface farther to the north-west, and the Antarctic water flows farther in this direction before it can sink. The movement of the Antarctic water towards the north or north-west is clearly demonstrated by the temperature and salinity distribution.

Towards the western end of South Georgia the isotherms and isohalines bend southwards, suggesting that the surface water has a small southward movement. Such a movement is possibly a final trace of the southward movement indicated so clearly farther north by the Brazil current, which can itself be traced to within 300 miles of the Falkland Islands (Klaehn, 1911, pl. 34). The effect of the southward movement on the conditions round South Georgia causes the south-west coast of the island to be bathed with water from the Bellingshausen Sea current, whilst the Weddell Sea current is held offshore.

North-east of South Georgia the isotherms, isohalines, and the convergence bend once more to the north. This bend seems to be related in the same way as that east of the Falkland Islands, to the influence of a greater movement of bottom water towards the north-west outside the Scotia Arc. In this region the bottom water flows strongly through the deep channel which leads past the comparatively shallow water north of South Georgia, into the Argentine Basin (Plate XLIV). In the northward movement at the surface, the Weddell Sea current approaches South Georgia and has a large influence on the conditions off the north-east coast. The northward movement will be due in some measure to the direct influence of the ridge and the presence of the island on the surface and deep currents towards the east, but its great extent, and the fact that the cold salient lies chiefly over the deep water north of the ridge, suggest that it exists mainly because of the stronger bottom current outside the ridge.

A comparison of the temperature and salinity distribution in the vertical sections in the western half of the South Atlantic (sections 2, 3, and 4, Plates III–VI) with that across the eastern end of the Drake Passage (section 1, Plate II) suggests that there is a greater flow of Antarctic water to the north. The observations made just north of the convergence show that there is a sharp temperature gradient within the first 400 m., indicating that the cold Antarctic water sinks towards the north below the warmer sub-Antarctic water. Longitudinal sections which extend throughout the whole length of the Atlantic Ocean show that such a sinking of Antarctic water gives rise to the poorly saline Antarctic intermediate current, which in the western half of the ocean can be traced as far as 25° N.

The longitudinal sections in 30° W. (Figs. 12, 13, p. 47), show that in this meridian the boundary between the Antarctic and sub-Antarctic waters at the surface is found just where the Antarctic water sinks abruptly to a deeper level, but the observations made just north of the convergence in sections 2 and 3 show that in the region east of the Falkland Islands a shallow stratum of sub-Antarctic water spreads some distance farther south above the Antarctic current.

At St. 1027 in section 3 the mean temperature in the first 50 m. was 3·53° C., but in the stratum between 100 and 200 m. it was only 0·68° C. Such a large difference between the two strata suggests that they belong to different currents, the surface water flowing southwards, and the deeper water, part of the main Antarctic current which sinks towards the north and gives rise to the Antarctic intermediate current, flowing northwards. The isotherms and isohalines in the section show that the Antarctic current starts to sink between Sts. 1027 and 1026, although the principal direction of movement is probably not in the plane of the section.

In 30° W, and during the summer in most other regions except between the Falkland Islands and South Georgia, the surface water appears to flow northwards as well as the deeper water; both currents sink together in the region where the warm deep water makes its steep ascent, and there is a sharp convergence between the Antarctic and sub-Antarctic waters at the surface. Between the Falkland Islands and South Georgia, however, the southward movement at the surface causes the sub-Antarctic water to flow southwards over the main body of the Antarctic water, and prevents the formation of such a sharp convergence.

In section 3 the mean temperature of the first 50 m. of water at Sts. 1026–9 was 4·62, 3·53, 2·34, and 1·28° C.; the surface water at St. 1029 is almost certain to be Antarctic water flowing northwards, and at St. 1026 sub-Antarctic water flowing southwards: the boundary between the two currents probably lies between Sts. 1027 and 1028, but it is not well defined. The temperature and salinity distribution shows that part of the Antarctic current sinks below the warmer sub-Antarctic water, but this convergence at the surface seems to be a very small affair compared with that which is formed at a deeper level where the main body of the Antarctic water sinks. It has, however, been called the Antarctic convergence, since it is the boundary between the Antarctic and sub-Antarctic waters at the surface. In section 3 it is not a well-defined boundary, but other observations made in the same region show that it is generally sharp enough to be recognized.

The conditions near the convergence north of South Georgia are somewhat similar to those east of the Falkland Islands; there is a tendency, although a smaller one, for the sub-Antarctic water to be carried southwards over the Antarctic water. The same is true of the region between 20 and 25° W; the data are not fully available at present, but those at hand indicate that the convergence may lie as much as 100–150 miles south of the latitude where the main body of the Antarctic water sinks.

The movement of sub-Antarctic water across the Antarctic water in these regions, especially east of the Falkland Islands, is no doubt facilitated by the trend of the Antarctic convergence towards the north, across the path of the prevailing wind.

Except for a small bend towards the south in the region north-east of the South Sandwich Islands, the isotherms between the Falkland Sector and 0–10° W run slightly north of east. The Antarctic convergence has been crossed at only a few points in this area, but as far as can be seen at present it follows approximately the same course as the isotherms; north-east of the South Sandwich Islands it lies in 50–50½° S, and then it advances to about 47½° S in 0–10° W; farther east, between 0 and 30° E, it recedes gradually southwards. The trend of the isotherms and convergence suggests that the principal movement of the Antarctic water in the northern part of the zone is towards the east, but it also points to the existence of a northward movement. Without such a movement the isotherms would recede towards the south as the surface water on its way eastward became warmer and warmer. The advance towards the north in 0–10° W does not necessarily suggest that the northward movement has a greater velocity in this region, since the trend of the convergence, and the distance to which the Antarctic water can flow northwards as a surface current, are determined primarily by the movements of the bottom water.

In 30° E the position of the convergence appears to be determined by a submarine ridge. The temperature and salinity distribution in section 8 (Plates XIII–XIV) shows that the northward flow of Antarctic bottom water is greatly restricted by a steep narrow ridge in about 50° S. The least sounding obtained on the ridge was 2952 m., but owing to a defect in the machine, the section 50 miles north of this point was not sounded, and the actual depth of the water on the summit of the ridge may be much less. The warm deep water climbs steeply over the ridge and the large volume of bottom water which is pent up to the south of it, whilst the Antarctic surface water sinks steeply in the opposite direction. The sudden sinking of the Antarctic water gives rise to a sharp convergence above the ridge.

The isotherms between 47 and 55° S in the western half of the Indian Ocean (Fig. 8) have been drawn with the help of those by Schott (1902, atlas) and Drygalski (1926, pl. 5). They bend northwards across the Marion Island-Crozet Islands ridge, southwards across the Kerguelen gap between the Crozet Islands and Kerguelen, and northwards again in the neighbourhood of the Kerguelen-Gaussberg ridge. These fluctuations are in all probability caused by the effect of the shallowing and deepening of the sea on the current towards the east; according to Ekman (1928) the deep current caused by the wind will be deflected to the left as the soundings decrease, and to the right when they increase. The deep current in the Southern Ocean, although not a true slope current, will no doubt be affected in a similar way, and its deviations communicated to the surface current. Evidence from other regions suggests that the convergence will follow approximately the same course as the isotherms. There is no indication that it bends northwards between the Crozet Islands and Kerguelen owing to the existence of a strong bottom current through the gap in the Atlantic-Indian Ocean cross-ridge; if the bottom water finds an easier outlet through the deep channel and is not pent up behind the ridge, the warm deep layer can, however, be expected to slope less steeply, and, helped by the effect of the increasing depth on the deep current, the convergence will recede towards the south.

The data available from higher latitudes in the western part of the Indian Ocean show that east of 40° E the 1 and 2° C. isotherms lie as much as 200–300 miles farther south than they do in the eastern part of the Atlantic Ocean. The northern limit of pack-ice also recedes towards the south in this region, and its high latitude has been used as evidence of a surface current towards the south (see p. 30). It is, however, not necessary to assume that there is such a current; there may be a general movement towards the north throughout the two regions, the high temperature and freedom from pack-ice of the water east of 40° E showing that the northward movement is much weaker there. The bending of the isotherms and the pack-ice limit towards the south may also be due to a decrease in the strength of the movement which carries Weddell Sea water eastwards across the Atlantic Ocean, and to the gradual disappearance of this water as it sinks towards the north or mixes with the neighbouring waters.

There is no indication of a movement of sub-Antarctic water southwards over the Antarctic water in the western part of the Indian Ocean, and the assumption of a small northward movement is more in keeping with the observations in section 8.

East of the Kerguelen-Gaussberg ridge there seems to be a strong northward current in which the water from the westerly current close to the continent finds its way northwards (see p. 31). Actually the current appears to be strongest at St. 861 (section 9, Plates XVI–XVIII) on the eastern slope of the ridge and at St. 864 which is almost north of the Shackleton ice-shelf. According to Ekman's theory the easterly current should bend southwards on the eastern slope of the ridge, but the data are not sufficient to allow the relation between the northward movement and the factors which cause it to be examined very closely; the ridge runs approximately north-west to south-east, and the northward movement east of the ridge may be due to water being deflected northwards in a higher latitude.

Section 9 also shows that there is a stronger movement of bottom water towards the north on the eastern side of the ridge, and it may be this current, acting as a false bottom to the sea, which causes the easterly currents in the deep and surface layers to be deflected northwards. The observations at Sts. 862 and 863 show that between the strong northward movements at Sts. 861 and 864 there is an area of weaker movement, and the northward current appears to have two main branches. The temperature distribution below the depth of 2000 m. suggests that there is a similar division of the bottom current; such a splitting of the bottom current, which may be caused by the irregularity of the sea-floor, affords a possible explanation of the division of the surface current. The temperature observations at Sts. 862 and 863 suggest that the stations are not far from the Antarctic convergence, which probably bends southwards like the isotherms.

East of 100–110° E the isotherms and the convergence start to recede gradually southwards. It has already been shown that the position of the convergence depends on the northward progress made by the bottom current, and the distribution of temperature and salinity in sections 10 and 11 (Plates XIX–XXIV), south of Australia, supports this conclusion, arguing that the convergence recedes towards the south mainly because the bottom current makes less progress towards the north.

The movements of the deep and bottom waters are, however, more complex than usual, especially in section 11; the isotherms and isohalines show that the upward slope of the warm deep layer is not steep and unbroken, but gradual and in a series of steps. The result of this abnormality is seen at the surface, where the Antarctic and sub-Antarctic currents are not so sharply distinguished as they are where the warm deep current climbs more steeply. The surface temperature records show that in section 10 there was a decrease from 5·5 to 3·7° C. between 52° 04′ S and 52° 24′ S, and in section 11 an increase from 2·5 to 4·5° C. between 54° 35′ S and 54° 20′ S. These changes appear to mark the principal boundary between the Antarctic and sub-Antarctic waters; and they probably indicate the normal position of the Antarctic convergence; but a closer examination of the data suggests that the sub-Antarctic water sometimes flows farther south. The distribution of temperature and salinity shows that the convergence is formed at the surface as soon as the warm deep water lies deep enough to allow the Antarctic current to sink towards the north below a southward current of sub-Antarctic water. In section 11 the warm deep layer starts to slope, and the Antarctic water to sink, between 57 and 58° S, and there seems to be a tendency for warm water to creep southwards at the surface; but between 55 and 57° S the slope of the warm deep layer is more gradual and the Antarctic current does not sink below the main body of sub-Antarctic water until it reaches 54° 35′ S. Where the deep water behaves in such a way and does not slope clearly and steeply, the absence of a sharp termination to the southward movement of sub-Antarctic water is therefore not remarkable.

The observations made at Sts. 883 and 891, just south of the convergence in sections 10 and 11, suggest that the surface water contains a considerable percentage of sub-Antarctic water. At St. 883 the mean temperature in the first 100 m. was 3·73° C., but between 150 and 300 m. it was only 2·16° C. Such a large difference so late in the autumn (May 23) indicates that the two waters belong to different currents, the cold water flowing northwards more rapidly than the surface water. The high temperature at the surface also argues that the surface water is partly derived from a southward movement of sub-Antarctic water.

There were two similar strata at St. 891; the mean temperature in the first 100 m. was 3·09° C., whilst it was only 1·82° C. between 150 and 200 m., the high temperature of the surface water again shows that the surface water south of the convergence was mixed with sub-Antarctic water. The biological data, obtained from an examination of nets fished between the surface and a depth of 260 m., show that both Antarctic and sub-Antarctic species were present, but the greater proportion of the sub-Antarctic species was found in the first 100 m. At St. 891, where the surface water was not so warm as at St. 883, the sub-Antarctic species were fewer.

Although the presence of a certain amount of sub-Antarctic water in the surface stratum south of the convergence shows that there must be a current towards the south, the sudden temperature change of 1·8 and 2·0° C. where the main body of Antarctic water sinks, proves that the current is not continuous. The warm water south of the convergence is probably carried there by occasional movements in which tongues of sub-Antarctic water are driven across the usual position of the convergence towards the south-east. There is evidence of such a tongue of water at St. 891, where the surface temperature was 0·5° C. higher than it was farther north, between the station and the convergence.

The southward movement in the neighbourhood of the convergence may be due to the West Wind Drift being forced into a slightly higher latitude in order to pass southward of Australia: it is also possible that the movement is only a seasonal feature. The thermohaline differences between the south and north of the Antarctic zone tend to set up a southward movement at the surface, but generally, owing to the influence of the prevailing west wind, the current flows in the opposite direction towards the north (see p. 13). In summer the northward movement is strengthened by the addition of fresh water from melting ice and snow, but in winter, when this support is removed, there is a greater possibility that the effect of the wind should sometimes be too weak to prevent a southward movement. The fact that the convergence lies comparatively far south, where the the west wind is beginning to weaken, also favours the effect of the thermohaline differences.

South of the Tasman Sea the convergence makes a small advance towards the north and regains its sharp definition. In sections 12 and 13 (Plates XXV–XXX) it is marked by temperature differences of 2·5 and 3·5° C. The temperature and salinity distribution show that the water movements in the warm deep layer have lost the irregularity which they exhibited south of Australia and the layer has the clearly defined steep slope which is more typical of the Southern Ocean.

South-east of New Zealand, where the convergence recedes once more towards the south, the observations in section 14 (Plates XXXI–XXXIII) show that the warm deep water makes only a gradual ascent over a weak bottom current. The distribution of temperature and salinity again indicates that the Antarctic convergence is formed at the point where the warm deep water lies deep enough for the Antarctic water to sink as a whole below the sub-Antarctic water, and the convergence is not so well defined as in regions where the bottom current is stronger and the warm deep layer climbs more steeply; it is only marked by a change in surface temperature of 1·5° C. in 15 miles.

Farther east, between 140 and 150° W, the isotherms and the Antarctic convergence advance towards the north. The bottom current is strengthened by a large volume of water which is turned northwards at the Cape Adare-Easter Island ridge, and the effect of the ridge and the greater bottom current is to cause the easterly current in the deep and surface layers to be deflected northwards. The greater northward movement at the surface is shown by the northward advance of the isotherms (Fig. 8) and of the limit of pack-ice (Fig. 9). The convergence was found to be very well defined, and there was a sudden increase of 3° C. in 55° 35′ S; it must bend still farther towards the north in 140° W because a further tongue of Antarctic water was crossed between 53° 43′ S and 53° 05′ S. In the deep basin east of 140° W (see Plate XLIV) the convergence retreats to a very high latitude; it makes a small bend towards the north near the longitude of Peter Ist Island, but the main trend, as far as 80° W, is towards the south. In accordance with the general rule, the temperature and salinity distribution indicates that the retreat of the convergence at the surface is associated with a decline of the northward current at the bottom.

In 120° 20′ W the position of the convergence is probably indicated by some observations of the Ellsworth Antarctic Expedition (1934–5) which showed that in 59° 20′ S the temperature of the sea varied as much as 3° within a run of a few miles.[1] The southward bend of the convergence to this point from 53 to 54° S in 140° W is very sharp. It is probably caused by a southward movement of the deep and bottom currents; these currents, which are deflected northwards as they approach the Cape Adare-Easter Island ridge, appear to turn back to the south in the deep water farther east.

Between 120° 20′ W and 110° 12′ W the convergence remains in approximately the same latitude; it was crossed in 59° 15′ S by section 16 (Plates XXXVII–XXXIX). East of 110° W it once more bends southwards. In section 17 (Plates XL, XLII) the surface temperature record showed a first increase of 2° C. in 61° 06′ S, 93° 10′ W, and then after an irregular decrease, a second increase of 3° C. in 60° S, 90° 32′ W. These observations suggest that the convergence bends roughly north-east between 93 and 90° W and indicate that it may lie as far south as 61–62° S between 110 and 93° W. East of 93° W there are several indications that the main drift of Antarctic water towards the east is deflected northwards; a northward set was experienced near Peter Ist Island by the 'Pourquoi Pas?' and the 'Odd I' (see p. 16), and the surface isotherms bend northwards. The bending of the convergence is probably associated with a stronger bottom current, and it gives some indication that the Antarctic shelf may extend farther north in this region.[2]

East of 90° W the convergence recedes once more to the south, until it reaches its farthest south in 80° W. In this longitude (section 18, Plates XLI, XLII) it was marked by a sudden fall of temperature in 62° 30′ S. An examination of the temperature and salinity distribution in the deep and bottom layers supports the conclusion that the convergence lies in such a high latitude because there is a very small northward movement of bottom water; only very far south does the warm deep current climb near enough to the surface to prevent the Antarctic water from sinking. East of 80° W the convergence runs approximately north-east through the Drake Passage.

---

[1] See note on Ellsworth Antarctic Expedition in Polar Record, No. 9, 1935, p. 67.

[2] Such an extension is shown tentatively in the American Geographical Society's Bathymetric Chart of the Antarctic, December 1929, revised November 1931.

The high latitude of the convergence in the eastern half of the Pacific Ocean does not necessarily imply that the northward movement of Antarctic surface water is very small. This may be so in the extreme eastern part of the ocean, where a part of the West Wind Drift is forced southwards round Cape Horn, but elsewhere the current may flow strongly towards the north although it does not get very far as a surface current. There are several indications of a strong northward movement of Antarctic water: there is a very great volume of cold and poorly saline water in the sub-Antarctic Zone, and except near to Cape Horn the ice chart (Admiralty, No. 1241, 1910) shows that records of icebergs are numerous.

The position of the Antarctic convergence is shown on a circumpolar chart in Fig. 4 (p. 19). In the Atlantic and Indian Oceans the position agrees roughly with that given by Meinardus (1923, p. 544), who gave a true description of the convergence as the line along which the ice-water, spreading northwards, sinks below the surface. Between 50° W and 10° E it also agrees with the position decided by Wüst (1928, p. 518) and Defant (1928, p. 475) from the current chart of Meyer (1923).

It must, however, be noted that if the position of the line along which the Antarctic water sinks is determined by the movements of the deep and bottom waters as shown in this report, the convergence between the Antarctic and sub-Antarctic waters is not necessarily marked by a striking current difference; the surface water north of the convergence may be water which has upwelled from the deeper strata to be carried towards the east and north at almost the same rate as the Antarctic water. The position of the convergence may therefore not always be shown on a chart of the surface currents. Meyer's chart of the currents of the Atlantic Ocean (1923) does not show the existence of a current convergence in the Drake Passage, although the temperature and salinity observations show that the convergence is generally well defined there. In the Indian Ocean the convergence cannot be distinguished in the charts of Michaelis (1923) or Willimzik (1924). The current charts are, however, only based on very scanty data in the neighbourhood of the convergence, and it is possible that a greater number of observations may reveal a small current difference.

The Antarctic convergence is by no means the only current convergence in the Antarctic regions. One, between the Weddell and Bellingshausen Sea currents, has already been described, and the current charts mentioned above show that there must be others. The continuity of the Antarctic surface layer shows, however, that these are probably not more than lines along which the surface water sinks into the cold stratum. They are probably not so permanent as the current charts, which are based on too few data, indicate; and they do not, like the Antarctic convergence, mark lines along which there are large changes in the structure of the sea.

## THE DEPTH OF THE SURFACE LAYER

The lower boundary of the Antarctic layer is the level at which the northward movement of the surface water changes over to the southward movement in the warm deep water. There is a considerable stratum of mixed water between the two layers; but they have such a different temperature, salinity, and oxygen content that the discontinuity layer in which these properties change rapidly with depth, is clearly distinguished. The exact depth of the surface layer can only be determined when more is known about the speeds of the two currents and of the friction between them, but the level at which the temperature, salinity, and oxygen content change most rapidly with depth between the two layers gives an approximate measure of it.

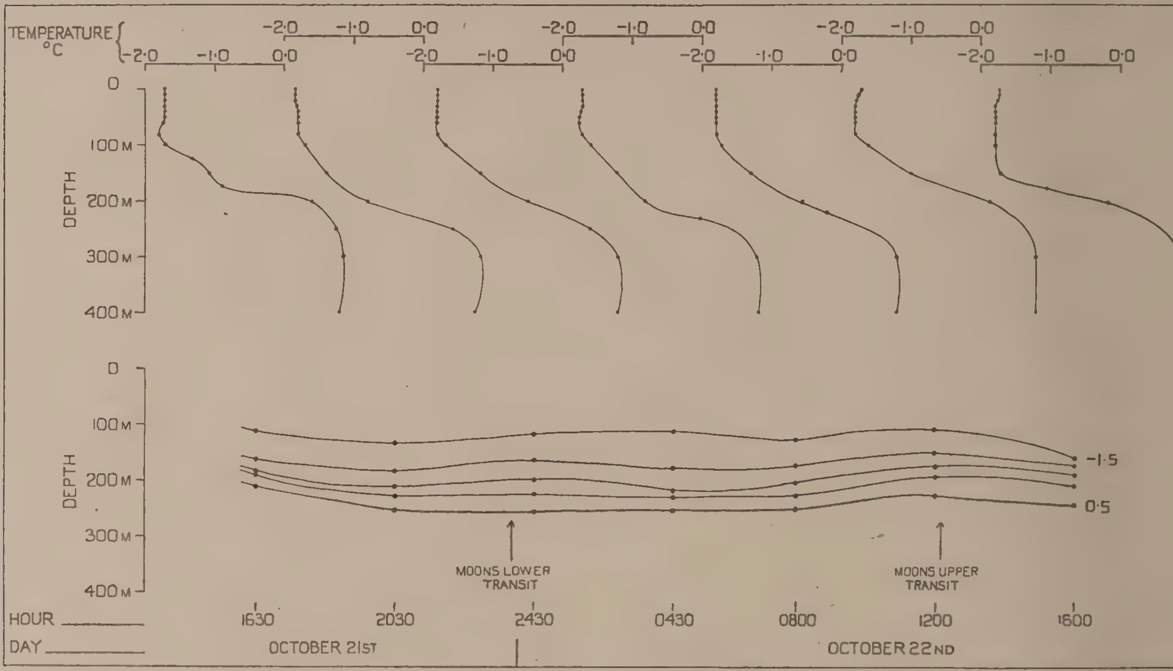


Fig. 10. The temperature-depth curves for series of observations made every 4 hours at St. 461, and the depths of the − 1·5, − 1·0, − 0·5, 0·0 and 0·5° C. isotherms after the same intervals.

The depth of the Antarctic layer changes not only from place to place but also from time to time. This variation has been illustrated by the up and down movements of the thermocline between the Antarctic and warm deep waters that are brought to light when observations are repeated at intervals in the same place. The curves in Fig. 10 show the results of observations made at intervals of 4 hours during a whole day in a small area between 56° 41′ S–56° 45′ S and 02° 21′ W–02° 24′ W (St. 461 A–G, Station List, 1932). The ship was not anchored, but the observations were made at points so close together that they can be regarded as made at the same point.

The curves in the upper half of Fig. 10 show the temperature of the water column between the surface and 400 m. at intervals of 4 hours, and those in the lower half of the figure the depth of the isotherms at the same intervals. Both sets of curves show that the temperature change between the two layers is sharpest where the temperature is – 0·5 to 0·0° C., and the depth of this stratum affords an approximate measure of the depth of the layer. The greatest depth was about 230 m. at 0600 hours on the second day, and the least depth 180 m. 6 hours later; the range of the vertical movements is 50 m. The examination of these and similar data is so far only in a very preliminary stage, and it cannot be proved that changes go on incessantly; these observations were made at the time of new moon, so that the possible effect of tidal influences on the layer should be measured when it was likely to be most pronounced. The times of the moon's upper and lower transits are indicated in the diagram, and it is approximately at these times that the isotherms are nearest the surface. The undulations of the isotherms during the 24-hour period suggest that their depths are changed by a succession of internal waves, and the period of the waves indicates that they are of tidal character. At the time of the first and third quarters of the moon the waves will probably have a smaller amplitude and the depth of the layer will not be subject to such large variations. It is also not certain that there are such fluctuations in the depth of the layer at all points in the Antarctic Zone. The observations described were made in deep water; the sounding was 3820 m. and the nearest shallow water—in the neighbourhood of Bouvet Island—250 miles away. Until the question of these changes has been thoroughly investigated any account of the depth of the layer must necessarily be only approximate.

The nineteen sections in this report which show the conditions in each sector of the Southern Ocean make it quite clear that the depth of the layer varies only within comparatively small limits. It is shallowest in the divergence region between the East Wind Drift near the Antarctic Continent, and the West Wind Drift farther north. The observations made in this region show that in the Atlantic and Indian Oceans the depth of the layer is only 60–80 m.; in the Pacific Ocean, however, the depth increases from west to east, and in the eastern half of the ocean it is about 150 m.

From the divergence region the depth of the layer increases towards the north and south; it is deepest near the convergence on the one hand and near the continent on the other. In each direction the slope is caused partly by the effect of the earth's rotation on the current flowing at right angles to the slope, but the northward slope at least must also depend on the north and south movements in the bottom and deep layers.

On the western side of the Atlantic Ocean the depth of the Antarctic layer near the convergence is 200–300 m.; on the eastern side the depth is slightly less, only 150–200 m. South-east of the Cape of Good Hope it is as much as 300 m.; at St. 850 in section 8 (Plates XIII–XV), the cold stratum of the layer was found between 200 and 300 m., its great depth being due to the presence of a large volume of highly saline cold water which is probably derived from the Weddell Sea current. South of Australia the depth of the layer near the convergence is 200–300 m., but it shallows towards the east, and south of the Tasman Sea is only 150–200 m. On the western side of the Pacific Ocean the depth is 200–300 m., in the deep basin east of the Cape Adare-Easter Island ridge about 300 m., and in the Drake Passage 200–300 m.

In the region of the prevailing east winds the slope of the layers of equal density towards the south is often very steep, and near the continent the boundary between the Antarctic and warm deep waters may lie as deep as 400 m. The boundary in this region is, however, not well defined; both layers flow westwards, and the mixing which takes place between them while they are so long in contact gives rise to an extensive stratum of mixed water.

The observations made by Brennecke (1921) between 73 and 74° S at the Deutschland Sts. 120 and 138 show that the sharpest changes of temperature, salinity, and oxygen content with depth are found at about 400 m. From certain shelf seas such as the Ross Sea and that north of Vahsel Bay at the southern extremity of the Weddell Sea the warm deep current is excluded, and in winter the whole water column is completely mixed from surface to bottom; even in summer there are only small changes with depth, except in a very shallow stratum at the surface, and the whole water column is justly regarded as highly saline Antarctic surface water. At 'Deutschland' St. 125 the temperature, salinity and oxygen data indicate that the complete mixing during the winter extended down to a depth of 685 m. The deepening of the Antarctic layer towards the continent is shown by each of the sections which extend into the region of the east winds; it is also shown very clearly by the observations of the 'Gauss' (Drygalski, 1926) in the Indian Ocean and by those of the 'Belgica' (Arctowski and Mill, 1908) and 'William Scoresby' (Station List, 1932) in the Pacific Ocean. The layer reaches a depth of 300 m. in the Indian Ocean and 400 m. south of Peter Ist Island in the Pacific Ocean.

In addition to the two principal tendencies of the layer, the deepening towards the north and south, the depth of the layer undergoes many other changes caused by the varying slope of the surfaces of equal density in currents of varying direction and strength. Such changes are shown very clearly by the observations in section 3 (Plate IV). Owing to the existence of current differences and eddies between the Weddell Sea and Bellingshausen Sea currents the depth of the layer varies from 100–150 m. at St. 1033 to 300 m. between Sts. 1031 and 1032; it then shallows to 150 m. at St. 1029 and deepens to 250–300 m. near the convergence. Similar changes may also be observed in section 9 (Plates XVI–XVIII) near the Kerguelen-Gaussberg ridge; where the northward current of Antarctic water is strongest, the depth of the layer on the right of the current is only about 100 m., but elsewhere it is more than 150 m.

## TEMPERATURE AND SALINITY

In winter almost the whole of the Antarctic surface layer is homogeneous; only near the convergence in certain regions does the temperature or salinity change with depth, and generally the first increase takes place in the discontinuity stratum which separates the layer from the warm deep water. The temperature is usually between − 1·8 and − 1·9° C. in the southern half of the zone, but it increases towards the north. The increase depends very largely on the strength of the northward current, but in the main the temperature rises to about 1° C. where the convergence is far north, and to 0° C. where it is far south.

In summer the layer has a surface stratum which is warmer and less saline than the deeper water. Near to land or pack-ice the stratum is usually very shallow; the warm water derived from melting ice and heated by the sun is not well mixed into the main body of the Antarctic water but lies on the surface in warm patches. During a cruise in January 1931, through and along the edge of the pack-ice between 67 and 69° S in the Pacific Ocean, the temperature at a depth of 1–2 m. was found to vary between $-1{\cdot}9$ and $+2{\cdot}0$° C. Farther north, owing to more intensive vertical mixing, the warm summer water is more evenly mixed throughout the Antarctic layer, and there is a deeper though less conspicuous surface stratum.

Observations made in the neighbourhood of South Georgia show that there is a well-mixed stratum extending to a depth of 55–85 m.; the changes of temperature and salinity with depth in this stratum are much smaller than those in the deeper water. The homogeneous nature of the stratum also suggests that it is kept well mixed by the strong west winds; the mixing may be caused by turbulent drift currents, and the depth of 55–85 m. probably represents the depth of the wind's frictional influence and the depth of these currents.

The temperature of the surface stratum depends on the strength of the northward current, but in the northern part of the zone it rises in the warmest months to about 3·5° C. where the convergence lies in 50° S, and to 2·5° C. where the convergence is in 60° S. The temperature of the cold stratum in the northern part of the zone is generally 2–3° C. less than that of the surface stratum. The difference may show nothing more than the greater effect of the summer warming on the surface stratum, but there is a further possibility that the low temperature in the cold stratum is partly preserved by a cold northward movement. Near the convergence east of the Falkland Islands and south of Australia the temperature difference between the two strata was large enough to suggest that they belonged to different currents and to contradict the assumption that the surface water had been formed from the deeper water *in situ* (see pp. 8, 9, 36, 37). The northward movement in the cold stratum may be caused by the colder and heavier surface water from the southern part of the zone sinking below the warmer and lighter water farther north. This appears to happen at the convergence between the Weddell Sea and Bellingshausen Sea currents, the large difference of temperature between the surface and cold strata just north of the convergence showing that Weddell Sea water sinks into the cold stratum.

The salinity of the Antarctic water is greatest in winter and least in summer. In winter it is increased by mixing with the highly saline warm deep water and by the salt which is deposited when the surface water freezes, but in summer it is diminished by the large volume of fresh water that drains into the sea from the melting ice and snow. There are probably not enough data to give a reliable picture of the distribution of salinity in the Antarctic Zone in winter, but there are one or two main features that appear to be certain. In the south there is a zone of high salinity from which the salinity decreases towards the north, and the northern part of the Antarctic Zone appears as a belt of minimum salinity between this water and the more saline water in the sub-Antarctic Zone.

The salinity in the southern part of the zone in winter varies from 34·0 to 34·5 °/₀₀, being greatest in the Weddell Sea. Where there is a strong northward movement, such as in the Weddell Sea, near the Kerguelen-Gaussberg ridge, near the Balleny Islands, near the Cape Adare–Easter Island ridge and near Peter Ist Island, the region of high salinity extends farther north. In the northern part of the zone the salinity is greatest in these localities, but nowhere does it fall below 33·8 °/₀₀. The approximate positions of the 34·0 °/₀₀ isohalines are shown in Fig. 11, the greater part of which shows the conditions in winter; the chart is, however, based on rather scanty data and at present the distribution is partly hypothetical.

In summer the salinity of the Antarctic water is much more varied, the surface stratum has generally a much lower salinity than the cold stratum, and there are also greater horizontal changes. At the surface the lowest salinity is found near the pack-ice or land; in such regions it is frequently lower than 33·0 °/₀₀, and there is little doubt that if the water were just scooped from the surface near to drifting ice it would be much less. Farther north the poorly saline water is more evenly mixed into the main body of the layer; the salinity at the surface is therefore greater than it is near to the pack-ice, but the salinity of the cold stratum is less; owing to more addition from melting ice as the current flows northwards, that of the layer as a whole is also less. In Fig. 7 (p. 27), which shows the average salinity of the first 100 m. of water in the Falkland Sector in early summer, there is a belt of minimum salinity just south of the convergence. There is probably such a belt of low salinity round the whole of the Southern Ocean, but there are as yet insufficient data from the summer months to allow a chart to be drawn.

The temperature and salinity of the Antarctic surface water are subject to large seasonal and annual changes; they have been closely examined in the neighbourhood of South Georgia and will be the subject of a separate report. The mean temperature and salinity of the first 50 m. of water have been found for the region between 52–56° S and 33–41° W. Between 1925 and 1933 the mean temperature of this area in January varied between 0·63 and 2·43° C., and the salinity between 33·64 and 33·97 °/₀₀. The seasonal change of temperature from winter to summer seems to be usually about 4° C.; the change of salinity is not so regular and depends very much on the amount of the annual change. In the years 1928–9, for instance, the salinity of the area investigated increased from 33·60 to 33·82 °/₀₀ from summer to winter, but only decreased to 33·78 °/₀₀ during the following summer. The fewer observations made near the Antarctic convergence indicate that the seasonal change of temperature is slightly smaller there, whilst the seasonal salinity change is greater.

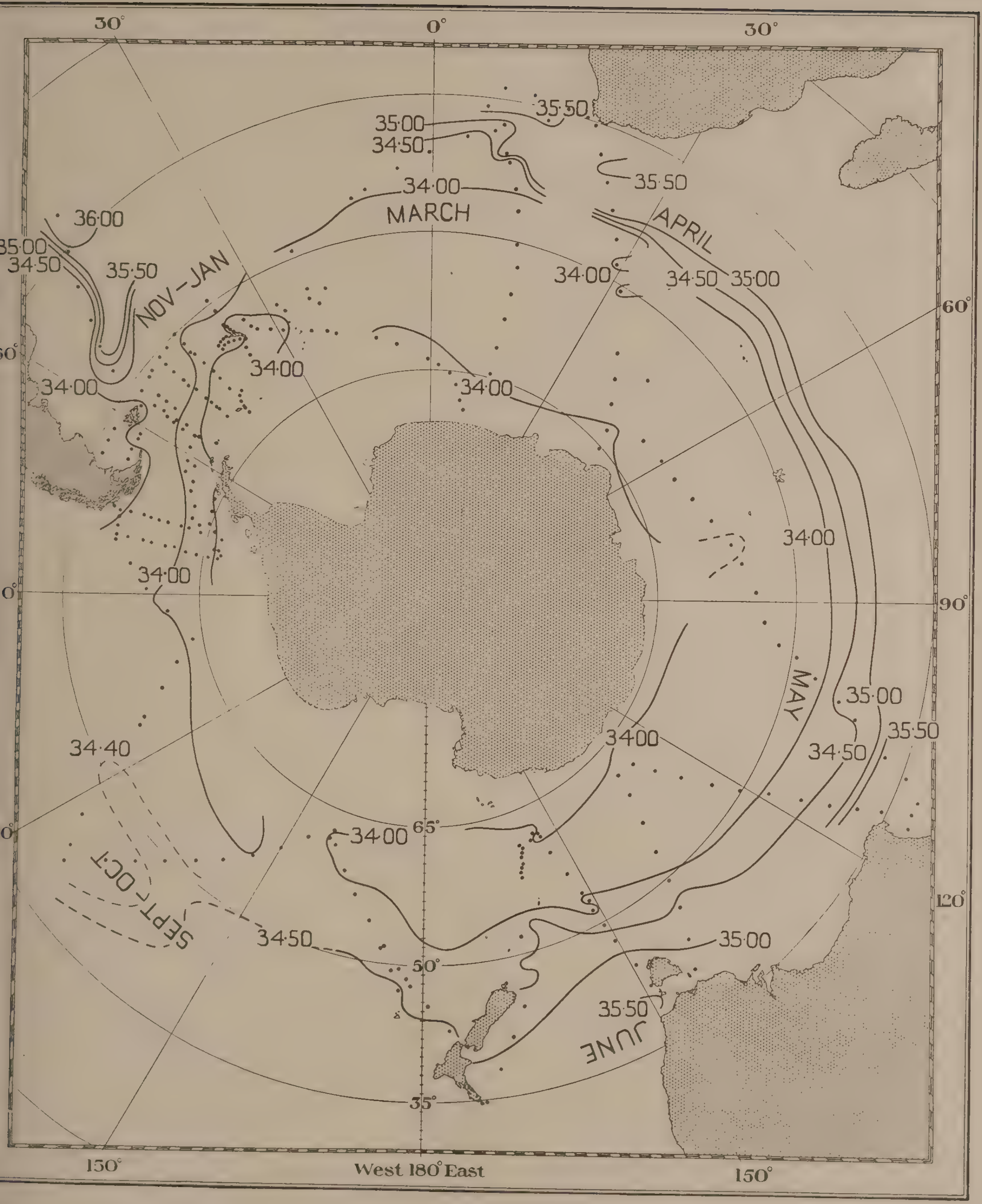

30°
0°
30°
60°
90°
120°
150°
West 180° East
150°
35·50
35·00
34·50
34·00
MARCH
35·50
APRIL
34·00
34·50
35·00
36·00
35·00
34·50
35·50
NOV-JAN
34·00
34·00
34·00
34·00
34·00
MAY
35·00
35·50
34·50
34·00
34·40
SEPT-OCT
34·00
65°
34·50
50°
35·00
35·50
JUNE
35°

Fig. 11. The surface salinity of the Southern Ocean, November 1931 to March 1933.

## SUB-ANTARCTIC WATER

At the Antarctic convergence the surface temperature increases suddenly towards the north—generally about 2·5° C. Where the convergence is far north the change is from 1 to 3·5° C. in winter and from 3·5 to 6·0° C. in summer, and where it is far south from 0 to 2·5° C. and 2·5 to 5·0° C. In the Pacific Ocean and the western part of the Atlantic Ocean the rise of temperature is generally accompanied by a small increase of salinity—from about 33·85 to 34·15 ‰—but in the Indian Ocean and the eastern part of the Atlantic Ocean the warm water just north of the convergence has practically the same salinity as the Antarctic water just south of it. The warm water is a mixture of Antarctic water with water from the north, and its mode of formation and properties suggest the name sub-Antarctic water. Like the surface water in the Antarctic Zone it lies in a poorly saline layer above the highly saline warm deep current, but owing to the much greater depth of this current it is a much deeper layer.

Observations made along the meridian of 30° W show that in 40–45° S the warm deep current lies below 1600–1200 m., but south of 50° S—in the Antarctic Zone—it reaches to within 250 m. of the surface. In the shallow space above it in the Antarctic Zone there is only one outstanding water movement, a drift towards the north-east, but in the much deeper layer of sub-Antarctic water there are at least three movements. The general drift of the water is towards the east, but incorporated with this movement there are northward currents of poorly saline water in the surface and deep strata, and a more saline current towards the south in the subsurface stratum. The presence of such movements is clearly indicated by the distributions of temperature, salinity and oxygen in the layer; these are shown for 35–55° S in 30° W by Figs. 12–14.

At the surface there is a well-mixed stratum, 60–80 m. deep, in which there are only minor changes of temperature and salinity with depth. The direction of the current in this water cannot be determined with certainty from the temperature and salinity distribution (see footnote, p. 48), but its uniformity suggests that it flows in more or less the same direction as the surface current which has been determined directly by means of current measurements and drift observations.

Meyer's current chart of the Atlantic Ocean (1923) shows that the sub-Antarctic water flows slightly north of east. Those of Michaelis (1923) indicate the same tendency for the Indian Ocean, although in certain localities—north-west of Kerguelen, and south of Australia and Tasmania—the current flows slightly south of east. In the Pacific Ocean the preliminary chart drawn by Merz, and published by Wüst (1929, p. 41), shows that the current is again generally slightly north of east. This general tendency is also indicated by the drifts of icebergs and by the results of drift-bottle experiments.

Krümmel (1911, II, pp. 677–8) gives a summary of such experiments. Bottles liberated south of 40° S near the east coast of South America were recovered on the south coast of Australia and the west coast of New Zealand. These drifts show that the surface currents tend to flow northwards as well as to the east, but they indicate that the northward movement is comparatively small. One record tells that a bottle liberated

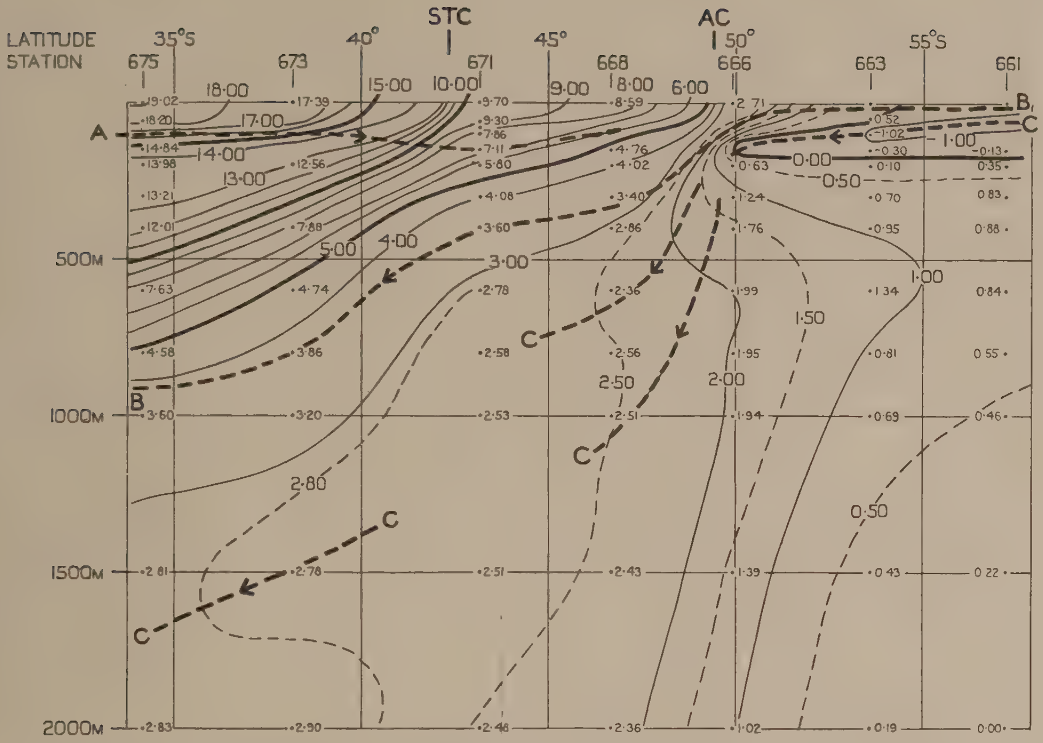


Fig. 12. The vertical distribution of temperature in 0 to 2000 m. between 35 and 55° S. in 30° W.

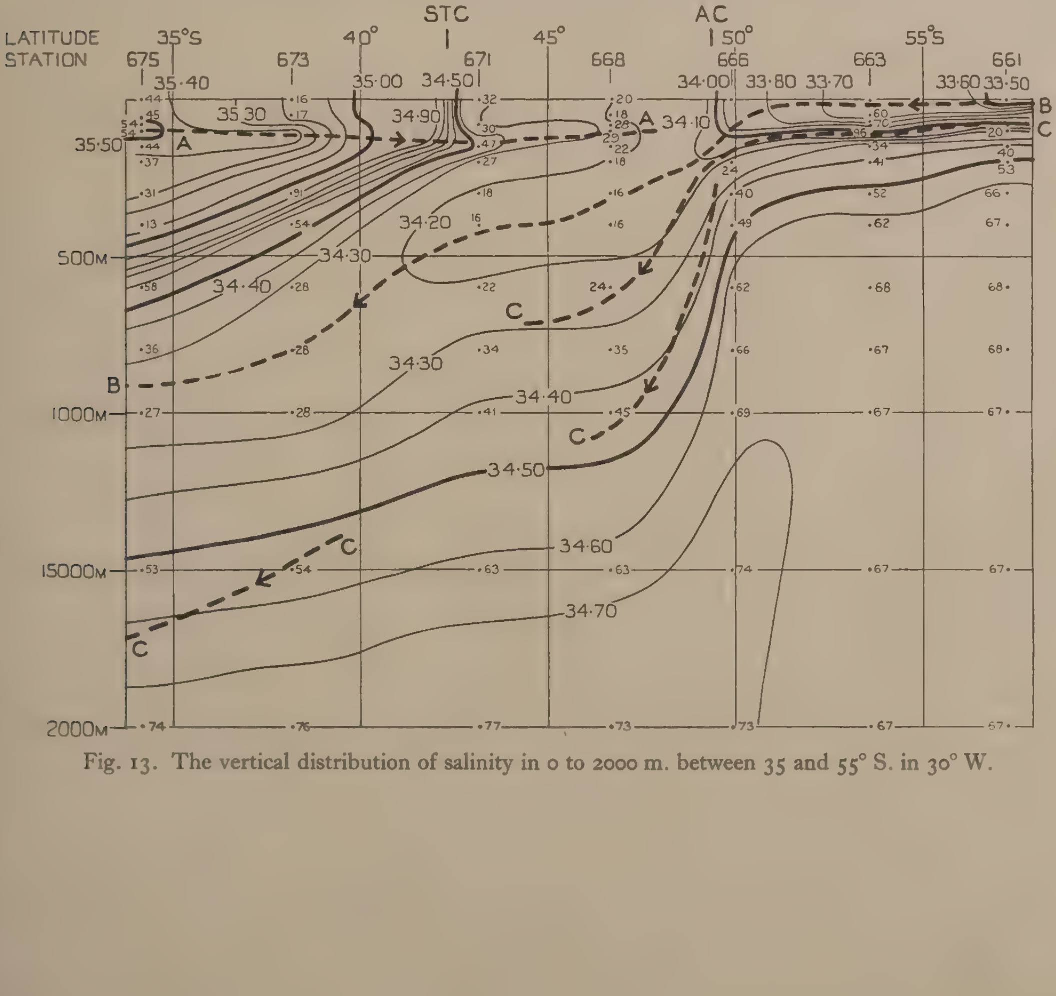


Fig. 13. The vertical distribution of salinity in 0 to 2000 m. between 35 and 55° S. in 30° W.

in 47° 45′ S, 114° 5′ E, south of West Australia, was recovered 870 miles farther north after an interval of 7 years, and Krümmel makes the reasonable suggestion that the bottle had made a complete circumpolar drift.

Below the well-mixed poorly saline surface stratum, the salinity section in Fig. 13 shows that there is a more saline subsurface stratum; it lies at a depth of 80–200 m. Below it there is another type of poorly saline water—the main body of the sub-Antarctic layer—which is known to flow northwards as well as the surface water, and since the subsurface current maintains its high salinity between these two poorly saline currents it must flow in the opposite direction towards the south.[1]

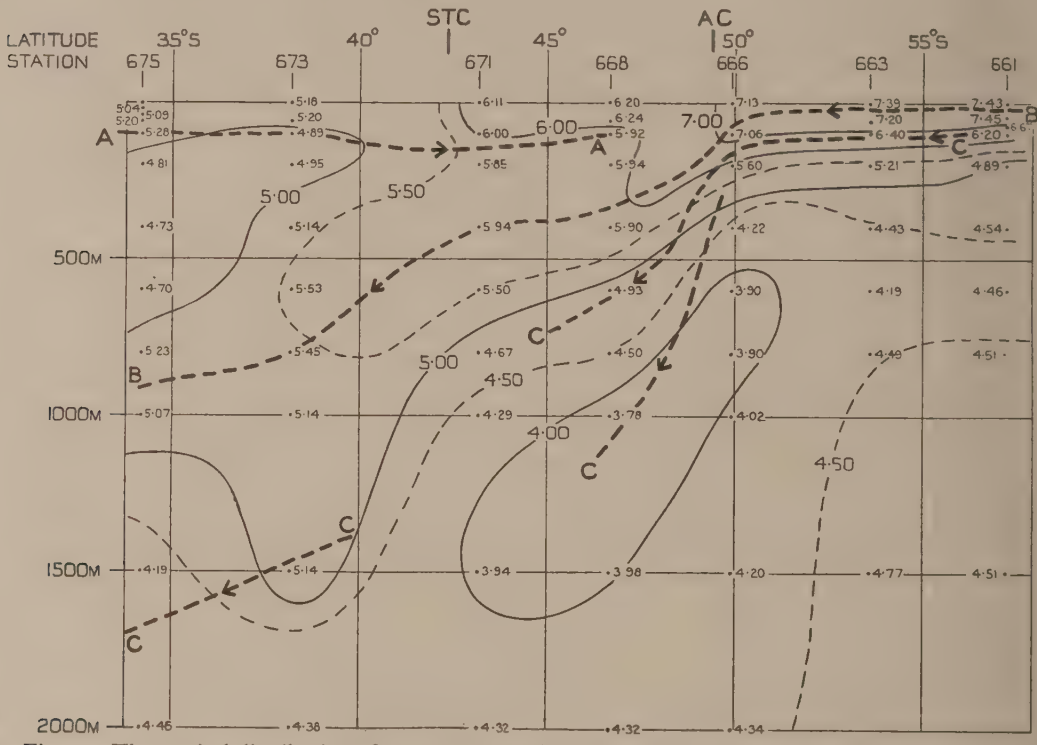


Fig. 14. The vertical distribution of oxygen content in 0 to 2000 m. between 35 and 55° S. in 30° W.

The path of the subsurface current is indicated approximately by the level of maximum salinity. It is marked in Fig. 13 by the line *AA*, and its relation to the temperature and oxygen distributions is shown in Figs. 12 and 14. The temperature section gives no evident indication of the existence of a southward current and shows that it is colder than the surface water; the oxygen section suggests the presence of a southward current of water poor in oxygen.

---

[1] H. U. Sverdrup (1934, p. 317) suggests the possibility that the surface and subsurface currents both flow southwards, the difference of salinity between them being due to the greater dilution of the surface water by precipitation. When this suggestion was made it was almost necessary to assume the existence of a southward movement at the surface in order to explain the sharpness of the Antarctic convergence, but now that the convergence is seen to be formed because the Antarctic water sinks as it passes over a steep slope of the warm deep layer, and not simply because it flows up against a lighter surface water, the assumption is no longer necessary. On the contrary a northward current must be assumed to explain the sharpness of the subtropical convergence. The evidence given in the previous paragraphs seems to be sufficient justification for this assumption.

The main volume of sub-Antarctic water, between the subsurface current and the warm deep layer, is clearly indicated in the figures as a large uniform area of low salinity and temperature and high oxygen content. Its situation in the section and its properties are sufficient evidence that it is formed by the mixing of the Antarctic water which sinks at the Antarctic convergence with water which flows southwards in the subsurface and warm deep currents. Longitudinal sections through each of the three main oceans show that this region of mixing is the birthplace of the Antarctic intermediate currents which flow northwards between more saline surface and deep layers as far as and beyond the equator; the extension of the intermediate currents for such a great distance is conclusive evidence that the main volume of sub-Antarctic water flows northwards. The movement seems to comprehend all the water between the subsurface and warm deep currents, but there are two strata which retain distinctive properties.

The most prominent stratum is one of minimum salinity; it is formed just north of the Antarctic convergence by the sinking of the poorly saline water from the surface stratum of the Antarctic water. Below it, the sub-Antarctic mixture contains a greater proportion of water sinking from the more saline cold stratum of the Antarctic layer, and has a greater salinity. Nearer the surface the salinity is also higher owing to the southward movement in the subsurface stratum. The level of minimum salinity is indicated in Figs. 12–14 by the line *BB*. The smallness of the changes of temperature, salinity, and oxygen content from south to north in the stratum suggest that it is the path of a large northward current, which because of the large volume of water it carries is not readily influenced by mixing with the neighbouring water masses.

Below the stratum of minimum salinity there is one of colder water marked by the lines *CC*. In 30° W, and throughout the western half of the South Atlantic Ocean, the stratum is one in which the temperature falls to a secondary minimum below warmer less saline sub-Antarctic water and above warmer highly saline deep water. The low temperature suggests that the stratum is a sub-Antarctic mixture which contains a large proportion of the water which sinks from the cold stratum of the Antarctic layer. The path of the current is not so clearly indicated as that of the poorly saline current from the Antarctic surface stratum, and the temperature and salinity sections both suggest that the northward movement of the colder and heavier water is more interrupted by turbulent mixing and eddy movements.

The observations at St. 668 point to the existence of a southward eddy of sub-Antarctic water at a depth of 800 m., where the temperature rises to a secondary maximum 0·2° C. higher than the temperature at 600 m. Sverdrup (1933, fig. 18) also regards the maximum temperature as evidence of a southward movement, but he further supposes that the movement is much more than an eddy and regards it as the principal origin of the water at the level of maximum temperature at a depth of 400–600 m. in the Antarctic Zone. It seems to me that such a conclusion is not justified, since even the upper stratum of this deep water has a high salinity which suggests that it is formed chiefly from a current which climbs from a much greater depth at St. 668. It seems safer to conclude that most of the poorly saline water is carried away towards the north, and to assume that the southward movement at 800 m. at St. 668 is only part of an eddy (see pp. 94, 95).

## THE SURFACE CURRENT

With the possible exception of a small stretch in the eastern part of the Pacific Ocean the sub-Antarctic Zone lies wholly within the region of the prevailing westerly wind. The currents set up by this wind are, according to Ekman's theory, a pure wind drift towards the north-east at the surface, and a convection current, with or without a slope current, towards the east in the deeper water; the resultant movement at the surface and at depths less than the limit of the wind's frictional influence will therefore be directed to some point north of east. The general existence of such a current is on the whole borne out by all the evidence available. In 30° W, for example, the uniform nature of the water in the first 60–80 m. suggests that it moves in more or less the same direction as the surface current, which the current charts show to flow north of east. Below 80 m. there are indications of a different current—a subsurface current towards the south, and the existence of such a movement at that depth is a reliable indication that the northward movement due to the wind is confined to the first 80 m.

Whilst the wind drives the surface water towards the north, another factor—the difference of climate between the southern and northern parts of the zone, sets up a density gradient which tends to cause a current in the opposite direction. The amount of radiation falling on the southern part of the zone is considerably less than that which falls on the northern part, and without the influence of the wind the colder and heavier water found in the south would sink and be replaced by a southward current at the surface. Sverdrup (1934, pp. 315–17) has calculated that the southward movement formed in this way is likely to be of the same order of magnitude as the northward current set up by the wind. The calculations are of course only approximate, but they indicate that the combined effect of wind and thermohaline differences will leave the surface water with no positive movement either to the north or south.

A further factor which is likely to influence the speed and direction of the surface current is the addition of Antarctic water to the sub-Antarctic Zone from the south. Krümmel (1911, II, pp. 680–1), who compared the current observations received at the Deutsche Seewarte from the strip of ocean between 40–45° S and 20–120° E, with the theoretical wind currents based on the charts drawn by Köppen, found that the surface current was stronger in summer than in winter, although the wind current should be weaker. Michaelis (1923, p. 29) also shows that the West Wind Drift has a more northerly direction in summer than in winter, and attributes the difference to a much greater northward movement of thaw-water from melting ice in summer. This conclusion does not conflict with the theory that the bulk of the Antarctic water sinks below the surface at the Antarctic convergence because the sub-Antarctic current has its origin in the region of mixed water which absorbs the Antarctic current.

Additional evidence of the existence of a greater northward movement of sub-Antarctic water during the summer months is furnished by the records of the occurrence of drifting icebergs. In the ordinary track of vessels the greatest number has been sighted in the months November–January, and the least in June and July. The relative frequency during the two periods being about 13 to 1 (Admiralty Chart, No. 1241, 1910).

The sub-Antarctic water is also made to flow north or south in certain localities where the general current towards the east is deflected by the effect of land masses and submarine ridges.

Although the influence of each of the factors which act on the surface water cannot as yet be judged with certainty they may reasonably be supposed to lead mainly to a movement slightly north of east in agreement with the conclusion drawn from the current charts, ice charts, and temperature and salinity data.

In the Drake Passage there is a strong surface current, part of the West Wind Drift, flowing from the Pacific Ocean to the Atlantic Ocean. The current observations and the temperature and salinity data from this region suggest that the current flows through the passage at an increased rate, owing to the main drift across the Pacific Ocean being compressed into comparatively narrow limits; sometimes it attains a rate of as much as 40 miles a day. The current appears to be particularly strong in the neighbourhood of Cape Horn, where it is supplemented by a stream of poorly saline and slightly warmer water from the coastal region west of Tierra-del-Fuego and Chile (see Figs. 6 and 7, pp. 26, 27).

At the eastern end of the Drake Passage the current bends sharply to the north and branches into two streams. One flows northwards, passing east and west of the Falkland Islands and along the Patagonian coast as far as the River Plate. This branch is known generally as the Falkland current. The second and main branch flows first towards the north-east and then almost due east across the Atlantic Ocean. Between this current and the Falkland current there is a tongue of warmer and more saline water which marks the southern extremity of the Brazil current (see Figs. 8, 11, pp. 29, 45). Another notable feature of the sub-Antarctic current east of the Falkland Islands is its tendency to spread southwards for a short distance over the Antarctic water (see p. 33).

In the Drake Passage the depth of the well-mixed surface stratum is generally about 100–150 m., being somewhat deeper in winter (Sts. 385–8, Station List, 1932), and shallower in summer (Sts. WS 405–9, Station List, 1930). East of the Falkland Islands the depth appears on the whole to be slightly less—about 60–80 m.—but at Sts. WS 251–3 (*ibid.*), in winter, the water was almost uniform down to 150–200 m. In the northern part of the zone, north-east of the Falkland Islands (Sts. 71 and 72, Station List, 1929), there was a well-marked surface stratum with a depth of about 75 m. The shallow water near the Falkland Islands and on the Patagonian shelf is in winter almost completely mixed from surface to bottom, but in summer there is a warm and poorly saline surface stratum which becomes more and more marked towards the north.

East of the region between the Falkland Islands and South Georgia, as far as 0–10° E, the general trend of the surface isotherms and isohalines indicates that the surface current flows slightly north of east, but farther east, south of the Cape of Good Hope and as far as 30° E, the iso-lines bend slightly southwards suggesting that the surface current has a lesser northward movement and possibly a southward movement. The fact that the Atlantic Ocean between 40–45° S is on the whole more free from icebergs east of 10° E (Admiralty Chart, No. 1241, 1910) is some confirmation of this conclusion.

In the region south of the Cape of Good Hope the sub-Antarctic current, flowing mainly towards the east, meets the Agulhas current—a strong current of subtropical water flowing in the opposite direction. The two streams become largely intermixed and the area is one of very irregular currents and sharp changes of temperature and salinity (see pp. 60, 75).

The main drift towards the east is also interrupted in 46–48° S by what appears to be a strong cyclonic eddy movement. The existence of such an eddy is indicated by the temperature, salinity, and oxygen content differences between Sts. 848 and 849 in section 8 (Plates XIII–XV). The normal decrease of temperature and salinity and increase of oxygen content towards the south were found to be reversed, and although St. 849 was actually 150 miles south of St. 848, its water column was warmer, more saline, and contained less oxygen.

The observations made by Brennecke in the 'Planet' (1909) also point to the existence of this eddy movement. The observations tabulated among the meteorological data (p. 13) show that on the voyage south-east of Cape Town the decrease to 3·4° C. in 47° 10′ S, 26° 30′ E, was followed by a sudden increase to 7·2° C. in 48° S, 27° 20′ E, and a final decrease to 3·3° C. in 49° 10′ S, 28° 50′ E.

The observations in section 8 show that the whole of the water column from the surface to the bottom is affected by the movement, and they suggest that the eddy is the effect of the irregular configuration of the sea-bottom first on the bottom and deep waters, and then on the surface water. The bottom temperatures and soundings available from this region indicate that the Atlantic Indian cross-ridge is arched first towards the north and then towards the south (Plate XLIV) and that Sts. 848–9 and the observations of the 'Planet' were made inside the second bend. The evidence as a whole suggests that the eddy current at the surface is a striking example of the far-reaching effect of the bottom topography.

The isotherms for the western part of the Indian Ocean in Fig. 8 are based on the charts given by Drygalski (1926, pl. v), and Schott (1902, Atlas, pl. ix), and on the average temperatures for the region between 42–44° S and 40–80° E, in the month of May, calculated by Krümmel (1911, II, p. 679). They bend towards the north on the ridge joining Marion Island and the Crozet Islands, and on the submarine plateau north-east of Kerguelen, but towards the south in the deep channel between the Crozet Islands and Kerguelen. In each locality the bending of the isotherms is probably due to a corresponding deviation of the surface current caused by the effect of the changing depth of the sea on the main drift towards the east. The northward movement of the water over the shallow ridges and the southward movement over the deep channel are in accordance with the theoretical effect of these depth changes on the easterly drift (Ekman, 1928, pp. 314–7).

East of 100° E the temperature distribution suggests that the southern part of the drift—the part colder than 8° C.—has a small southward tendency, whilst the warmer northern half bends slightly northwards. The spreading of the isotherms is probably an indication of an area of mixed water which begins in about 43° S, 104° E at Sts. 869 and 870 (section 9, Plates XVI–XVIII) and extends eastwards, south of Australia, between the 8 and 11° C. isotherms.

The observations at Sts. 869 and 870 suggest that the main drift towards the east is interrupted by an eddy movement similar to that found south-east of the Cape of Good Hope. Throughout the whole of the water column at each station the temperatures and salinities are higher at St. 869 than they are at St. 870, 160 miles farther to the north-east. This eddy also appears to be caused by the effect of the bottom topography on the easterly current. The topography is not well known, but the preliminary chart in Plate XLIV suggests that the two stations lie where the bottom slopes steeply towards the north-west from the Indian Pacific cross-ridge to the deep basin west of Australia. The data are not sufficient to determine the direction of the eddy current with absolute certainty, but the most reliable indication—given by the density distribution—suggests that it is anticyclonic.

The belt of mixed water which the spreading of the surface isotherms shows to extend towards the east from Sts. 869 and 870 is probably formed as a result of numbers of such eddy currents. There is evidence of an eddy between Sts. 879 and 881 in section 10 (Plates XIX–XXI) south-east of Cape Leeuwin, and of another between Sts. 893 and 895 in section 11 (Plates XXII–XXIV) south-west of Tasmania. Both eddies are probably caused by the influence of the steep slope from the Indian Pacific cross-ridge to the South Australian basin on the eastward current.

The general conclusions reached with regard to the surface currents from the temperature and salinity data are in approximate agreement with those suggested by the current and ice charts. The charts of Michaelis (1923) and Willimzik (1924) allow a northward movement to be distinguished near Marion Island and the Crozet Islands and also east of Kerguelen, and a southward movement in the deep channel between the Crozet Islands and Kerguelen.[1] The charts of Michaelis also point to a divergence of the current south of Australia in approximately the same latitude as the belt of mixed water described above; the southern part of the drift is shown to have a small southward movement, whilst the northern part is deflected northwards.

The records of drift-ice confirm several of these conclusions. The Antarctic Pilot, 1930, p. 19, states that "between the Cape of Good Hope and Tasmania ice is seldom met with north of 40° S. Between the 40th and 45th parallels it is mostly seen between 40° E and 60° E"—north of the Marion Island-Crozet Islands ridge. "Between the 45th and 50th parallels ice may be met with anywhere westward of 90° E. Eastward of that meridian"—where the southern part of the drift has a southward tendency—"it is much rarer."

---

[1] In Michaelis' charts Kerguelen is charted incorrectly in 80° E instead of 70° E.

South of Tasmania and New Zealand the isotherms and isohalines suggest that the current is deflected southwards. They are, however, very irregular and indicate that the current becomes involved in a large number of small eddies which can almost certainly be attributed to the influence of the exceptionally rugged bottom topography of the region.

On reaching the west coast of New Zealand the current divides into two branches, one flowing towards the north and the other towards the south. The current does not divide on the south-western extremity of South Island in 46° S, but a little farther north near Jackson Bay in 44° S; between these two points the current sets almost constantly southwards (New Zealand Pilot, pp. 29–30). Along the east coast of South Island the current also runs north-eastward, and farther south, past Auckland and Campbell Islands, towards the east.

The temperature and salinity distribution east of New Zealand indicates that the northward current is not confined to the coastal region but extends as far off-shore as the Antipodes and Chatham Islands; the width of the current is probably related to the soundings, since it appears to be confined to a region in which the depth is 2000 m. or less, and is replaced by a southward current where the depth increases suddenly to more than 5000 m. just to the east of the Chatham Islands. In section 14 (Plates XXXI–XXXIII) across this region the coldest water was found at Sts. 944 and 946 near the eastern limit of the shallow soundings. This is possibly an indication that the northward movement is strongest there, but it may also be an indication of upwelling between the northward current in the shallow water and a southward current in the deep water farther east. The existence of the southward current was shown by the observations given in Appendix I, which reveal a sharp bend of the isotherms and isohalines towards the south in the deep water.

The movements of sub-Antarctic water in the neighbourhood of New Zealand show on the whole a close resemblance to those east and west of South America. As the West Wind Drift approaches the west coast of South Island, it divides into two branches just as it does off the west coast of Chile. Off each coast the division takes place in about 44° S, and one branch flows northwards whilst the other turns to the south. In each region also, the southward current flows towards the east round the southern extremity of the land, and, joined by more water from the main easterly drift, turns northwards along the east coast. The northward current east of New Zealand has therefore a great similarity to the Falkland current. It is, however, on a smaller scale, and has a higher temperature and salinity, but these differences would be expected owing to the much shorter distance to which New Zealand projects into the path of the easterly drift.

The analogy between the two currents is heightened by the fact that in the deep water east of New Zealand, there are indications of a southward current of warm and highly saline subtropical water with some resemblance to the Brazil current.

The deflection of the West Wind Drift towards the south as it crosses the region south of the Tasman Sea and approaches New Zealand affords a reasonable explanation of the fact that icebergs are not generally encountered north of a line 180 miles north of Macquarie Island. Farther east, this line, which shows the usual limit of icebergs, bends slightly northwards, running midway between the Campbell and Auckland Islands, and cutting the 180th meridian in about 50° S (Antarctic Pilot, 1930, p. 19). In November and December 1897, large numbers of icebergs were seen in 46° 30′–51° S between 175 and 165° W, evidently carried northward by the current which resembles the Falkland current. Several large icebergs and loose ice were observed from the Chatham Islands themselves in October 1892, but there appears to be no other record of ice being sighted (New Zealand Pilot, 1930, p. 380).

Observations made at Sts. 1277–81 (Appendix I) in the deeper water east of New Zealand show that east of section 14 the isotherms and isohalines bend sharply southwards. The high temperatures and salinities, belonging to a southward movement of subtropical water, seem to be definitely associated with the deep soundings, and the poorly saline water, belonging to the northward sub-Antarctic current, with the comparatively shallow ones. Schott (1934, p. 241) has emphasized the great difference of salinity between the waters east of South and North Islands; and to the east of North Island, where the water is much warmer and more saline, the soundings are also much greater. The preliminary chart drawn by Merz (Wüst, 1929, p. 41) gives, however, only weak indications of a southward current, and although the general northern limit of icebergs (Admiralty Chart, No. 1241, 1910) bends slightly southwards between 180 and 150° W the bend is not large enough to be used as evidence of a southward movement.

In the eastern half of the Pacific Ocean the movements of sub-Antarctic water are also rather uncertain. The isotherms are almost parallel to the lines of latitude until very close to the west coast of South America, where they branch towards the north and south. The temperature distribution seems to suggest that the main drift across the Pacific is directed towards the east, but that it divides off the coast of Chile, in about 44° S, into a southward current towards Cape Horn and a northward current along the coasts of Chile and Peru towards the Galapagos Islands.

The salinity distribution indicates, however, that the water in the northernmost part of the zone flows towards the west. In the central part of the ocean (sections 15 and 16, Plates XXXIV–XXXIX) the salinity of the surface water does not increase towards the north as it does in the Atlantic, Indian, and West Pacific Oceans; after rising to a maximum of just over 34·4 ‰ in 50° S it decreases to 34·14 ‰ in 41° S. The same low salinity was found in this region by the 'Challenger' at St. 289, the actual value, calculated by Wüst (1929, p. 59) from the density measurements, being 34·18–34·25 ‰. Schott (1928, pl. xiv) and (1934, pl. i) has shown that this area of low salinity is part of a tongue of poorly saline water which extends towards the west from a poorly saline coastal region, south of 35° S, west of Chile. Wüst (1929, p. 42) also concludes that the poorly saline water at Challenger St. 289 has its origin in about 40° S in the eastern part of the ocean, and it can only be supposed that the sub-Antarctic water in the neighbourhood of 40° S flows towards the west. The preliminary current chart by Merz shows that the northward current along the west coast of Chile turns back towards the west north of 35–30° S, but the salinity distribution as shown by Schott suggests that the westward movement begins farther south.

In the southern part of the zone the current is not deflected southwards in order to round Cape Horn until it reaches about 90° W. The isotherms suggest that the current is forced farthest south in 70–80° W, and farther east it bends northwards into the Drake Passage.

The uniform surface stratum, in which the water movement is probably in more or less the same direction as the surface current, has almost the same depth in the Indian Ocean as in the Atlantic Ocean. South of Africa it appears from the observations at Sts. 107 and 451 (Station Lists, 1929, 1932) to have a depth of 100–150 m. in winter, and from those at Sts. 1162 and 1163 in section 7 (Plates X–XII) one of about 100 m. in summer. South-west and south of Australia the water was generally found to be uniform to a depth of 100 m.

The observations made in the southern part of the zone in the Pacific Ocean show that in winter the water is practically uniform down to a depth of 400 m., and probably because of intense vertical mixing the surface water has almost the same properties as the subsurface and intermediate waters. In summer, however, according to data collected during the last cruise of the 'Discovery II', the vertical differences are slightly greater and there is a surface stratum 50–100 m. deep in which the salinity is 0·06–0·14 $^{\circ}/_{\circ\circ}$ less than that of the subsurface water.

The observations made in winter along the line of section 14 south-east of New Zealand show that there was very little difference of temperature and salinity between the surface and subsurface waters even at the northernmost stations. In summer the difference is slightly greater. At St. 1279 (Appendix I), 2° east of St. 946 (section 14), the water in the first 60 m. is 3–4° C. warmer and 0·17 $^{\circ}/_{\circ\circ}$ less saline than the subsurface water at a depth of 150m. In the central part of the ocean (sections 15 and 16, Plates XXXIV–XXXIX) there was a well-defined surface stratum north of 45° S even in winter. At St. 967 the surface water was as much as 0·27 $^{\circ}/_{\circ\circ}$ less saline than the subsurface water and 0·17 $^{\circ}/_{\circ\circ}$ less than the lowest salinity of the intermediate water. This poorly saline water is not, however, part of the general drift towards the east, but apparently belongs to a current towards the west from the poorly saline coastal region west of Chile. A preliminary examination of observations made in the northern part of the zone in the eastern part of the Pacific, in the Humboldt current region, shows that there also the surface stratum is much less saline than the subsurface stratum, again no doubt because of the surface current from the poorly saline coastal region.

## THE SUBTROPICAL CONVERGENCE

The observations made in the northern part of the sub-Antarctic zone and the southern part of the subtropical zone show that the waters in these two regions have very different properties and that there is generally a sharp transition from one to the other. The existence of such a sharp boundary suggests that the two currents form a convergence in which at least one of them sinks below the surface. The evidence that is available so far, though not conclusive, shows that the sub-Antarctic water generally has a movement north of east, whilst the subtropical current has a southward component. Since the sub-Antarctic water is the heavier of the two currents it is more likely to sink at the convergence.

In 30° W (Figs. 12–14, pp. 47, 48), the boundary between the two waters was crossed between 43 and 42° S, where the temperature at the surface increased suddenly from 9·5 to 13·5° C. and the salinity from 34·4 to 34·9 °/₀₀. The continuous surface temperature record showed that there were minor fluctuations extending 2 or 3° farther north, but the sudden change in 43–42° S evidently marked the principal boundary.

The nature of the water movements in the neighbourhood of the convergence seems to be indicated most clearly by the salinity distribution shown in Fig. 13. One of the most positive indications given by the section is that there is an unbroken current towards the south in the subsurface stratum, between 80 and 200 m. The current starts from the subtropical region and can be followed almost to the Antarctic convergence. Owing to the presence of this current any sub-Antarctic water sinking at the subtropical convergence will be turned back towards the south between 80 and 200 m., and the properties of the subsurface current indicate very clearly that it is partly composed of such water (p. 63).

Owing to its lesser density the subtropical water is less likely than the sub-Antarctic water to sink at the convergence, and the observations suggest that it accumulates at the surface north of the convergence until its increasing volume or the weakening of the sub-Antarctic current causes it to advance towards the south above the sub-Antarctic water, thus driving the convergence towards the south. The subtropical water at St. 1165 in section 7 (Plates X–XII) may belong to such a movement. Between the surface and a depth of 150 m. there is a stratum of highly saline subtropical water, but at 200 m. above a well developed subsurface current, the water has the usual low salinity of northward-flowing sub-Antarctic water.

An increase in the strength of the sub-Antarctic current or a removal of the factors which caused the subtropical water to advance towards the south will cause the convergence to retreat towards the north. There are frequent indications that this has taken place in such a way that some subtropical water has been left behind, and being isolated from the main current this water has become mixed with sub-Antarctic water. The first 50 m. of water at St. 72 (Station List, 1929) in 41° 43′ S, 42° 21′ W, has a salinity of 34·67–34·69 °/₀₀. This is an abnormally high salinity for sub-Antarctic water and it suggests that the surface water is mixed, to the extent of about 50 per cent, with subtropical water which has previously made an advance towards the south and has been left behind when the convergence retreated northwards. Below 50 m. the water has the usual low salinity 34·43–34·42 °/₀₀, which suggests that the water at this depth has not been disturbed by the southward advance of the subtropical water.

Where the subtropical water is known to have a strong movement in opposition to the sub-Antarctic current the position of the convergence appears to be subject to frequent fluctuations, and the isolation of southward salients of subtropical water leads to the occurrence of alternating streams of subtropical and sub-Antarctic water. Brennecke (1921, p. 49) has noted the existence of such streams between the Brazil and Falkland currents, and they are even better known south of the Agulhas current (see pp. 59, 75). The finding from time to time of highly saline patches of water to the south of the convergence in other localities suggests that they may occur less frequently all round the Southern Ocean.

In contrast with the Antarctic convergence, whose existence is determined primarily by deep water movements, the subtropical convergence appears to be formed solely as a result of the opposition of the subtropical and sub-Antarctic surface currents. Several more intensive series of observations are still needed before an indisputable picture of the water movements near the convergence can be obtained, but there are sufficient to leave little doubt of the correctness of the scheme which has been outlined.

The position of the convergence shows a general agreement with the water movements as shown by the most recent current charts. Where the charts suggest that subtropical currents penetrate to high latitudes the convergence lies far south, and where the sub-Antarctic drift extends into low latitudes it lies far north. The convergence is also found to be sharpest where the current charts show the surface currents to be most directly opposed.

In the western half of the Atlantic Ocean the convergence lies in the boundary region which the Brazil current forms with the Falkland current to the west and the main body of the West Wind Drift to the south. Between the Brazil and Falkland currents the temperature and salinity differences are remarkably large. Klaehn (1911, p. 650) shows that temperature differences of as much as 10° C. in 20–30 miles are not unusual, and the observations made by Brennecke (1921, pp. 48–51) give an example of a temperature and salinity difference of as much as 7° C. and 1·4 $^\circ/_{\circ\circ}$ within a distance of 8 miles. The exceptional magnitude of these differences is largely due to the fact that the two currents flow for a long distance side by side in opposite directions; the temperature differences are also increased by the upwelling of colder water on the right flank of the Falkland current, and the salinity differences by this current being diluted with coastal water. Between the Brazil current and the main body of the West Wind Drift to the south the differences are not so large: according to Klaehn (1911, p. 651) the temperature differences are rarely as much as 4–6° C.

With the help of a chart showing the mean annual temperature of the surface water in the region between Cape Horn and the River Plate, based on a large collection of data from the log books of merchant and other vessels, Klaehn has proved that the Brazil current can on an average be traced as far as 49° S. The terminal region is, however, one of sudden temperature and salinity changes; the current direction alters repeatedly as the wind varies, and streams of highly saline water, partly or wholly subtropical, alternate with streams of cold and poorly saline sub-Antarctic water.

In such a region there is no fixed boundary between the northward and southward currents. The observations in the Southern Ocean as a whole, and the few that are available from this region, suggest, however, that the water north of the 11·5° C. isotherm in winter and the 14·5° C. isotherm in summer belongs entirely to a movement of subtropical water towards the south, and is not mixed with sub-Antarctic water. The mean annual position of such a boundary determined from the monthly temperature charts of Klaehn (1911, pl. 35) is shown in Fig. 4 (p. 19). It does not extend south of 43–44° S, although the Brazil current can, according to Klaehn, be traced to 49° S, and it can only be concluded that in the last 5–6° of latitude the subtropical water of the current becomes more and more mixed with sub-Antarctic water. The monthly temperature charts show that the relatively unmixed subtropical water penetrates 3–5° farther south in summer than in winter, owing to the greater strength of the Brazil current in summer (see Klaehn, pp. 657–60).

Farther east the subtropical convergence recedes gradually northwards. Between 41° 43′ S, 42° 21′ W and 35° 18′ S, 19° 01′ W the convergence lies approximately along the line of observations made at Sts. 72–8 (Station List, 1929). Sts. 243 and 245 in 38° 48′ S, 27° 22′ W, and 38° 20′ S, 22° 18′ W (*ibid.*) appear to lie just north of the convergence. Observations made in January 1926 near Tristan da Cunha in 36° 55′ S, 12° 12′ W, and farther south in 39° 25′ S, 12° 08′ W (Sts. 4 and 7, *ibid.*), indicate that the convergence was then just south of the island, but others, made between Sts. 78–83 and Sts. 246–9, in June 1926 and June 1927, show that the convergence was probably north of the island. Observations made by the 'Challenger' (St. 133) and the 'Gauss' (Drygalski, 1926, pp. 423 *et seq.*) point to the same conclusion. In November 1933, however, the convergence was quite definitely 5–6° south of the island.

The data collected so far show therefore that the position of the convergence fluctuates over at least 6° of latitude. They give some indication that the movement is seasonal, towards the south in summer, and towards the north in winter; but the high latitude of the convergence in November 1933—at the end of winter—suggests that it has other large movements, probably dependent on corresponding meteorological changes. The mean position of the convergence indicated by the rather scattered data is shown in Fig. 4.

In the eastern half of the Atlantic Ocean as far as 15° E the convergence lies between 35 and 38° S. It then bends sharply southwards as far as 40° S and there, owing to the presence of a tongue of water which pushes its way towards the west from the Agulhas current, it bends back in a salient towards the west before it continues its general trend towards the east in about 44° S.

The data available from this region suggest that the position of the convergence varies over a range of at least 100–200 miles. The position shown in Fig. 4 is as nearly as possible the average boundary between the two waters, but it is not unlikely that subtropical water will frequently be encountered outside it. The tongue of water which flows westwards from the Agulhas current into the Atlantic Ocean south of 40° S appears to be particularly subject to variations. The temperature and salinity distribution in October 1930 showed that the subtropical water extended as far as St. 450 in 44° 58′ S, 12° 58′ E, and in March 1933 it was found as far west as St. 1165 (section 7) in 41° 01′ S, 9° 34′ E. In deciding the position of the convergence the observations made by the 'Gauss', 'Valdivia' and 'Planet' have been used in addition to our own data.

Where the water from the Agulhas current meets the West Wind Drift there is a region of very irregular currents, and streams of warm highly saline subtropical water alternate with areas of colder and less saline sub-Antarctic water. The existence of such isolated streams of subtropical water illustrates the tendency of the subtropical water to spread southwards over the sub-Antarctic water, and to remain at the surface rather than sink at the convergence.

A typical record of the surface temperature across this region, obtained on a passage from Cape Town to Bouvet Island in October 1930, (Station List, 1932), is shown in Fig. 15. The principal boundary between the subtropical and sub-Antarctic waters lies just north of St. 449, but there is another area of sub-Antarctic water 1–2° farther north and a region of mixed water in between. There is also an outlying stream of subtropical water at St. 450. Such outlying streams sometimes have a depth of 300–400 m., as at St. 450, but frequently they are confined to a shallow surface stratum of only about 80 m., as at St. 431 (*ibid.*) and St. 1165 (section 7, Plates X–XII). The deeper currents are probably relatively stable features and are likely to be united to the main body of subtropical water farther north, but the shallow streams may be only short-lived and isolated.

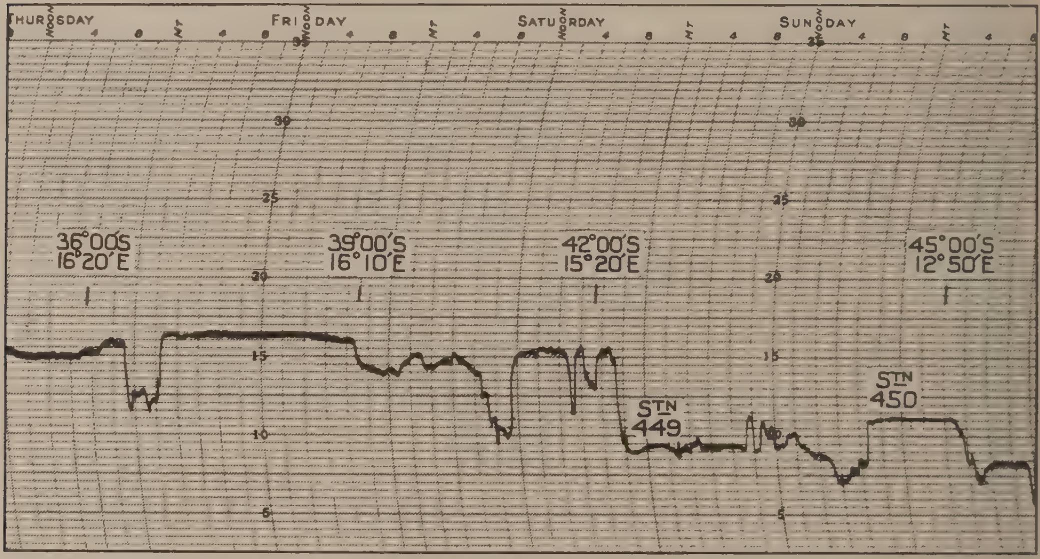


Fig. 15. A continuous record of the surface temperature between 35 and 46° S. on a passage from Cape Town to Bouvet Island, October 1930.

South-east of the Cape of Good Hope the convergence is crossed by section 8 (Plates XIII–XV) in 43° 50′ S, 25° 40′ E; the temperature falls from 15·5 to 10° C., and the salinity from 35·2 to 34·6 $^{\circ}/_{\circ\circ}$ in about 9 miles. A similar drop of temperature was observed by Brennecke (1909, p. 111) between 41° 35′ S, 22° 10′ E, and 42° 42′ S, 22° 48′ E. The 'Meteor' crossed the convergence in about 41° S, 22° E; it was found to be particularly sharp, and visible from a long way off as a line of current disturbance at the surface. The temperature rose very suddenly 5·6° C. in 1 mile and 9·1° C. in 5 or 6 miles (Wüst, 1926, pp. 248–9).

In the central part of the Indian Ocean the surface temperature observations of the 'Valdivia' (Schott, 1902) and the 'Gauss' (Drygalski, 1926) show that the convergence lies between 40 and 41° S in about 76° E. The surface temperature charts of the Indian Ocean by Möller (1929, figs. 17, 21) and the salinity chart by Schott (1934, pl. 1) show that the region between this position and that of the convergence south-east of Africa is marked by a steep temperature and salinity gradient from south to north.

In 106–108° E (section 9, Plates XVI–XVIII) the convergence was crossed between 39° 50′ S and 38° S; it was not well defined, and the increase of temperature and salinity took place in three steps. At the first, however, in 39° 50′ S the temperature and salinity rose from 11·5 to 12·5° C. and 34·6 to 34·9 $^{\circ}/_{\circ\circ}$, and, as shown by the observations at St. 871 18 miles farther north, the water was largely subtropical.

The inversion of the usual increase of salinity and temperature towards the north between Sts. 869 and 870 shows that the main drift towards the east is interrupted by a large eddy movement, and the high salinity of the surface water at St. 869 indicates that the subtropical convergence may bend towards the south between sections 9 and 10 even more extensively than is shown in Fig. 4.

South-east of Cape Leeuwin, in section 10 (Plates XIX–XXI), the temperature and salinity fell suddenly towards the south in 38° 22′ S from 18·5 to 14·5° C. and 35·8 to 35·4 $^{\circ}/_{\circ\circ}$. This sudden fall appears, however, to mark the boundary between a subtropical current which flows southwards along the west coast of Australia and a current from the west, rather than the southern limit of the subtropical water. At Sts. 880 and 881 in 44–47° S the surface water is plainly sub-Antarctic, but at St. 879 it contains a large proportion of subtropical water. There is no sharp convergence between the two waters, but the surface observations, used in constructing the section, indicate that the balance between the northward and southward currents lies between 39 and 40° S.

Near Tasmania there was also no sharp convergence; in section 11 (Plates XXII–XXIV), west of the island, the balance between the sub-Antarctic and subtropical currents seems to be reached in 44–42° S where the temperature increases from 11 to 13·5° C. and the salinity from 34·7 to 35·0 $^{\circ}/_{\circ\circ}$. In section 12 (Plates XXV–XXVII), south-east of the island, the boundary is probably in 45–47° S, with similar temperature and salinity differences. There was an indication of a second current boundary in 47° 33′ S, where the temperature and salinity fell from 10·5 to 7·5° C. and 34·7 to 34·2 $^{\circ}/_{\circ\circ}$; but although there is apparently a strong southward movement as far as this latitude in the subsurface stratum the relatively low surface salinity at St. 899 indicates that the surface water has a northward component as far as at least 47° 18′ S.

The absence of a sharp convergence between the sub-Antarctic and subtropical waters south of Australia is probably due to the smallness of the northward and southward components of the two currents. It is reasonable to suppose that the shape of the ocean—roughly a channel with parallel sides—will cause the water movement to be directed almost due east, and the lateral movements to be more restricted than they are where an extensive ocean lies to the north.

The convergence also appears to be ill-defined in the Tasman Sea west of New Zealand. The water at St. 923 in section 13 (Plates XXVIII–XXX) belongs to the sub-Antarctic current which flows eastwards, south of Stewart Island, but that at St. 924, about 80 miles from the west coast of South Island in 44° 18′ S, belongs to the current which sweeps towards the north along the west coast, and contains a large proportion of subtropical water. Between Sts. 924 and 925 the section lies too nearly in the direction of the current to give a clear indication of the changes of temperature and salinity at right angles to the coast, but they both appear to increase gradually away from the land.

West of South Island the water more than 100 miles offshore has the temperature and salinity of subtropical water and is no doubt derived from the East Australian current and from the easterly movement south of Australia. Nearer the coast the water has a lower temperature and salinity, and is partly sub-Antarctic, some of it probably having upwelled in the coastal region from the poorly saline antarctic intermediate current. Surface current observations show that part of the northward current turns towards the east round the northern end of South Island into the Cook Strait (New Zealand Pilot, 1930, p. 29), and this branch of the current probably contains the bulk of the sub-Antarctic water. Off the west coast of North Island the water is much warmer and more saline. As far as the scanty data allow it to be determined, the principal boundary between the waters of sub-Antarctic and subtropical origins lies between Sts. 924 and 925 in section 13, and it approaches the land in the neighbourhood of Cape Egmont. It follows approximately the 12° C. isotherm and the 34·9 °/₀₀ isohaline.

There are very few observations to show the position of the subtropical convergence east of New Zealand. The 'Dana' crossed a well-marked boundary in 42° S, 177° E, about 100 miles from the eastern end of the Cook Strait (Schott, 1934, p. 241). The temperature and salinity measurements along section 14, and others made farther east (Appendix I) which have been used in the construction of Figs. 8 and 11 (pp. 29, 45) show that the isotherms and isohalines bend towards the south in the deep water east of the Chatham Islands. There appears to be a southward movement of warm highly saline water, with some resemblance to the Brazil and Agulhas currents (see pp. 54, 55), and the subtropical convergence probably bends towards the south.

Farther east the isotherms, isohalines and convergence recede towards the north. According to the calculations of salinity based by Wüst (1929, pp. 59–60) on the old density measurements of the 'Challenger' the surface water at St. 287 (Murray, 1895, p. 1092) in 36° 32′ S, 132° 52′ W had a salinity of 34·94 °/₀₀, while the surface salinity at St. 289 in 39° 41′ S, 131° 23′ W was only 34·25 °/₀₀. These data suggest that there is a sharp increase of salinity from south to north in this region and indicate that there may be a sharp convergence, possibly in 36–37° S. The temperature difference between the Challenger stations was, however, only 1·8° C., and no sudden temperature changes were recorded anywhere in the neighbourhood (Tizard and others, 1885, p. 802).

A salinity section constructed by Sverdrup (1931, p. 101) based on the Carnegie results points to the existence of a sharp convergence in about 32° S, 109° W, but the data given are too few to give an accurate idea of the water movements to the north and south of it.

## THE SUBSURFACE CURRENT

The temperature, salinity, and oxygen content of the southward current in the subsurface stratum of the sub-Antarctic Zone suggest that it is replenished from two main sources, from a subsurface current in the subtropical zone itself, and from sub-Antarctic water which sinks at the convergence; its properties are intermediate to those of these two types of water. In the northern part of the zone the stratum is generally sharply distinguished from the less saline surface and deep waters, but farther south the contrast is reduced by vertical mixing, and within a zone which extends 100–200 miles north of the Antarctic convergence there is often no sign of a southward current.

According to Ekman's theory the prevailing west wind will give rise to a slope or convection current towards the east, and the resultant movement in the subsurface stratum should therefore be towards the south-east.

In the western part of the Atlantic Ocean, in the neighbourhood of the Brazil current, the surface water in the northern part of the sub-Antarctic Zone is frequently mixed with subtropical water and is therefore more saline than the subsurface stratum. This stratum can, however, still be recognized at St. 72 (Station List, 1932) and Deutschland St. 99 (Brennecke, 1921, p. 97), where the highly saline surface water and the subsurface current are still separated by a less saline stratum of sub-Antarctic water.

East of the Falkland Islands where there are a large number of observations in the southern part of the sub-Antarctic Zone, the subsurface current can generally be traced to within about 100 miles of the Antarctic convergence. At St. WS 69 (Station List, 1929), for example, at this distance from the convergence, the subsurface stratum had a salinity of as much as 34·16 ‰, whilst the surface and intermediate water had only 34·07 and 34·11 ‰. At some of the stations—WS 251, 252 (Station List, 1930), 431, 432, 518 and 520 (Station List, 1932)—the subsurface stratum is more saline than the surface water but of the same salinity or even slightly less saline than the deeper water. The relatively high temperature of the stratum distinguishes it, however, from the deep water, and in conjunction with an occasional difference of salinity shows that there is still a subsurface current towards the south.

In the central and eastern part of the Atlantic Ocean the existence of the subsurface current is plainly indicated by the observations at Sts. 668 and 671 (Fig. 13), Sts. 7–10 (Station List, 1929) and WS 437–9 (Station List, 1932). The level of maximum salinity rises towards the south from about 150 to 100 m., suggesting that the current climbs gradually as it approaches the region of lower water temperatures. At St. WS 439, near the subtropical convergence, in 38° 27′ S, 5° 45′ E, the subsurface water was as much as 0·5 ‰ more saline than the surface or intermediate waters. The average difference was, however, much less than this, and in the central part of the zone it was only about

0·13 °/oo. The current can be traced to within about 100 miles of the Antarctic convergence (St. WS 437).

In the region south of the Cape of Good Hope there are very few series of observations in the sub-Antarctic Zone, but they are sufficient to show that the subsurface current exists there. At St. 1163, in section 7 (Plates X–XII), the salinity of the water at a depth of 200–400 m. was 0·10 and 0·03 °/oo greater than the salinities of the surface and intermediate waters. At St. 1162 the presence of the current was indicated by a sharp increase of salinity with depth between 100 and 150 m., but, as at some stations in the western part of the Atlantic Ocean (see above), its salinity was not as great as that of the colder water which sinks towards the north in the intermediate current below it. The subsurface current can also be detected at Sts. 414 and 431 (*ibid.*), but not at St. 449, which appears to be in a strong current eddy, or at St. 450 where it cannot be distinguished from the surface current. The scanty data indicate that the current is not so well defined in this region as it is farther west; it is also deeper, starting at 300–400 m. and climbing to 100–150 m.

The observations at Sts. 848 and 849 in section 8 (Plates XIII–XV), south-east of the Cape of Good Hope, also point to the existence of a weak subsurface current at a depth of about 300 m. The current appears to be stronger at St. 849 than at St. 848 although the station is farther south, and the temperature and salinity distribution in this region indicates that the current does not flow simply towards the south-east, but that it takes part in a large cyclonic eddy movement. The same cyclonic movement is found in the surface and deep layers (see p. 52), and it is probably caused by the irregularities of the bottom topography.

In the central part of the Indian Ocean the subsurface current lies at a much greater depth. The observations made by the 'Gauss' at St. 88 (Drygalski, 1926, p. 481) point to its existence at a depth of 400–600 m.

In the eastern part of the Indian Ocean and in the region south of Australia there are also evident indications of a southward movement at a very deep level. The observations in sections 9–12 (Plates XVI–XXVII) show that north of 45–48° S the stratum has a much higher salinity than it has in the Atlantic or western part of the Indian Ocean, and it also has a remarkably great depth—as much as 600–800 m. In 45–48° S, however, the movement suddenly shrinks and farther south it is confined to a much shallower stratum—between 100 and 300 m.—and it also has a much lower salinity. The reason for the sudden diminution in the current is not yet certain; it may be the result of the restriction of the space above the warm deep current as it climbs towards the surface above the bottom water, or simply an extensive subsurface convergence between the Antarctic intermediate water and the subsurface water as they are forced together in the region south of Australia on their way towards the east.

The salinity and temperature distribution in the Indian Ocean suggests that much of the highly saline water found in the northern part of the subsurface current may be formed in the western part of the ocean from the Agulhas and Agulhas return currents (see p. 75).

South of New Zealand the highly saline subsurface stratum marking the subsurface current can be followed as far as 51–52° S; it is not quite as deep as it is south of Australia, but lies principally between 400 and 700 m. in the northern part of the zone and between 300 and 600 m. farther south.

In the Pacific Ocean east of New Zealand the current appears to be very small. At Sts. 944 and 948 in section 14 (Plates XXXI–XXXIII) the salinity at a depth of 150 m. was not more than 0·03 and 0·05 ‰ greater than the salinity of the surface water, or 0·15 and 0·11 ‰ greater than that of the Antarctic intermediate current. At the other stations there was practically no indication of the current. Observations made during the summer of 1934 in the deeper water farther east (St. 1279, Appendix I) showed the current to be slightly stronger, but still weak compared with the subsurface current in the Atlantic Ocean.

In the central part of the Pacific Ocean there was a well-marked subsurface stratum at a depth of 300–400 m. (sections 15 and 16, Plates XXXIV–XXXIX). It suggests that there is a continuous movement towards the south at this depth, and the upwelling of the subsurface water may be the cause of the relatively high salinity of the surface water in 48–52° S (see also Fig. 11). The current appears, however, to be weak compared with the Atlantic and Indian Ocean currents, and the difference of salinity between the stratum and the intermediate water below it is not more than 0·1 ‰. North of 45° S it is much more saline than the surface water (0·27 ‰ at St. 967), but the difference is not comparable with those of the other oceans, since the surface current does not belong to the general drift of sub-Antarctic water towards the north-east but probably flows towards the west from a poorly saline coastal region west of Chile (see p. 55).

A preliminary examination of observations made in the northern part of the zone off the west coasts of Chile and Peru shows that the subsurface stratum generally has a much greater salinity than the surface water. This difference shows that the water in the subsurface stratum has a southward movement relative to the intermediate layer; but without a closer investigation of the data, which indicate on the whole that the highly saline water comes from the west, it is not safe to conclude that there is actually a strong southward current in the stratum. In the southern part of the zone, near the western end of the Magellan Strait, there are practically no indications of a southward movement. In winter a subsurface stratum could only be distinguished at St. 985 in section 18 (Plates XLI, XLII), where the salinity at 400 m. was not more than 0·05 and 0·03 ‰ greater than those of the surface and intermediate waters. Summer observations in the same region showed that the difference between the stratum and the surface water was slightly greater, and the stratum was 0·02–0·07 ‰ more saline than the intermediate water. The difference between the winter and summer conditions is no doubt due to the prevalence of much more intense vertical mixing in winter.

The southward movement in the subsurface stratum is probably caused by the influence of the density gradient from north to south, which is set up by the differences of climate, and by the effect of the prevailing winds. As explained on pp. 12–14, the sinking of the cold Antarctic water in the south will tend to cause a compensating movement towards the south at the surface. Such a movement is actually prevented at the surface by the northward transport of water in the wind drift currents, but in the sub-Antarctic Zone it can take place in the subsurface stratum. In addition to being the result of thermohaline differences the current may compensate for the northward movement of the surface drift currents. Owing to the gradual decrease in the strength of the wind towards the north in the sub-Antarctic Zone the surface transport towards the north is smaller in the northern part of the zone, and some of the water which is carried more rapidly towards the north by the stronger winds farther south may return towards the south in the subsurface current. The salinity distribution in the neighbourhood of the subtropical convergence and the properties of the water in the subsurface stratum show that the current also contains the sub-antarctic water which is carried northwards by the wind to sink at the subtropical convergence.

## THE ANTARCTIC INTERMEDIATE CURRENT

The repeated crossing of the sub-Antarctic Zone has given much new information about the part played by the Antarctic water in the formation of the intermediate current. In the region extending 100–200 miles north of the Antarctic convergence there is a large volume of mixed water which is formed by the mixing of the sinking Antarctic water with the warmer and more saline waters carried southwards by the subsurface and warm deep currents. The mixture is not quite homogeneous, and the warmer and lighter part is carried northwards at the surface whilst the colder heavier part sinks to form the intermediate current.

The path taken by the intermediate current lies below the subsurface current and above the warm deep current, and in longitudinal sections through each of the three main oceans it appears as a poorly saline layer between these highly saline waters. The upper and lower boundaries of the current have not yet been determined exactly, and except for the measurements described in the author's previous report (1933, pp. 223–6) no quantitative examination of the transport of the water in it has been possible. Some idea of the relative strengths of the current in the different sectors of the Southern Ocean can, however, be obtained from the distance to which the poorly saline water penetrates towards the north.

The positions of the 34·20–34·70 °/₀₀ isohalines are shown on a circumpolar chart in Fig. 16; the chart is only approximate, since the data are rather scattered and no allowance has been made for seasonal or annual changes, but it will serve the purpose of an investigation which is necessarily only introductory.

In the western and central parts of the Atlantic Ocean the volume and strength of the current seem to be particularly great. The chart in Fig. 16 and the vertical salinity section along 30° W (Fig. 13) show that the poorly saline water is carried far north, and the slow increase of salinity along its path suggests that the current has a large volume. The current can be followed by its low salinity as far as 25° N, and as far as 5° S the water

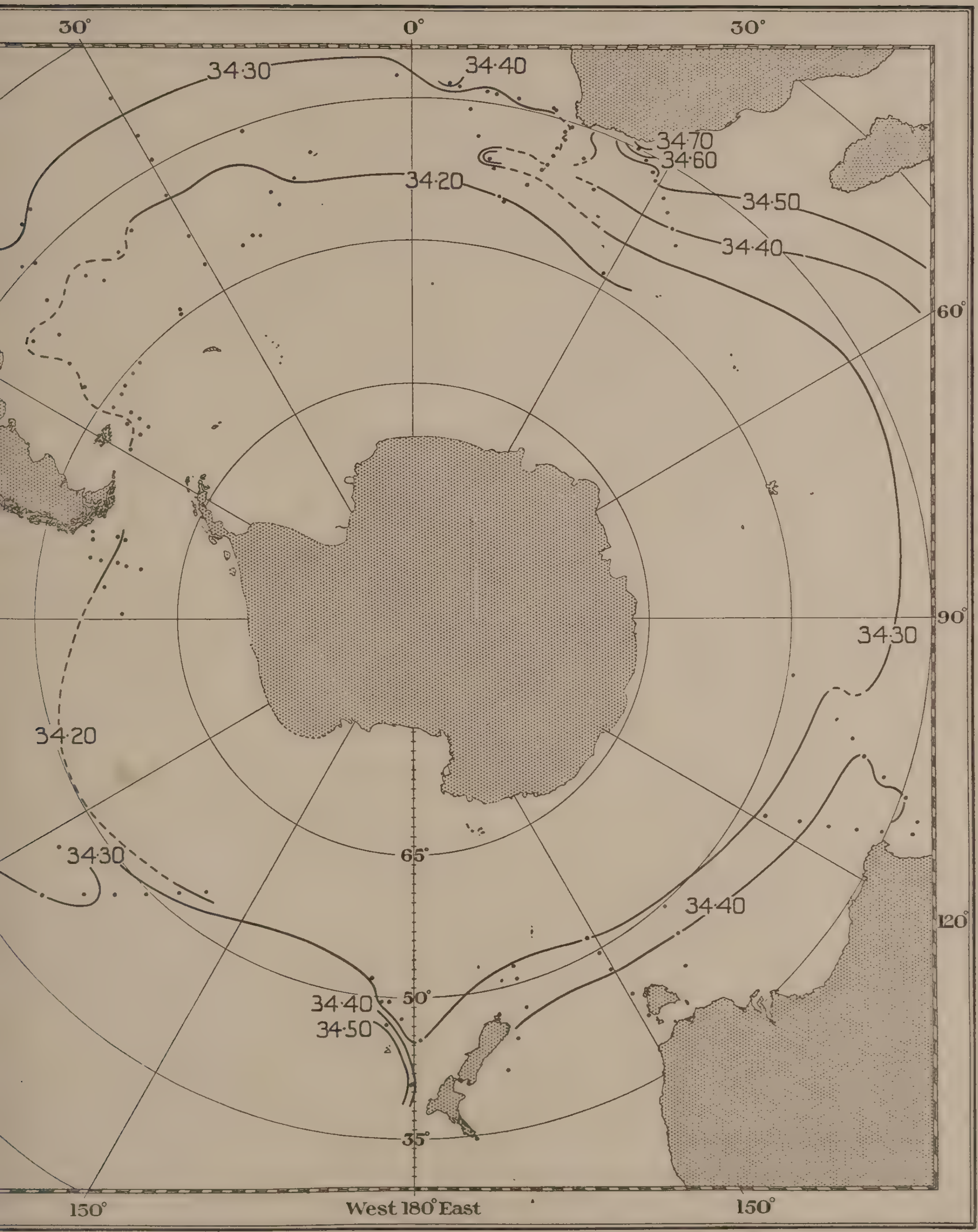

30°
0°
30°
34·30
34·40
34·70
34·60
34·20
34·50
34·40
60°
90°
34·30
34·20
34·30
65°
34·40
120°
50°
34·40
34·50
35°
150°
West 180° East
150°

Fig. 16. The geographical position of the 34·20 to 34·70 °/₀₀ isohalines at the level of minimum salinity in the Antarctic intermediate current.

in its lower stratum is colder than that in the upper stratum of the North Atlantic deep current which flows southwards below it.

The current is probably not quite so strong in the eastern half of the ocean. The chart in Fig. 16 and a comparison of the salinity distribution along section 7 (Plates X–XII) with that along 30° W (Deacon, 1933, pl. viii) shows that the salinity of the current is on the whole slightly greater, whilst its volume is smaller. A comparison of the sections along the eastern and western Atlantic basins constructed by Wüst (1928, pl. xxxiii), and an examination of the cross-section in 35·4° S drawn by Möller (1926, pl. ii), leads to the same conclusion. A small temperature inversion was found between the intermediate and warm deep currents at each of the stations south of 30° S in section 7, but it was much smaller than that found at Sts. 668–87 in 30° W. The weak nature of the inversion in the eastern part of the Atlantic Ocean has also been noted by Wüst (1926, p. 241). In the Rio Grande channel, the deep passage through the Rio Grande ridge along the northern side of the Argentine Basin, he found that the inversion was as much as 0·67° C., but in the east Atlantic Ocean he found an inversion only at the deepest stations (75 and 77), where it was not more than 0·01–0·04° C. The greatest inversion that we found in the eastern part of the ocean was 0·07° C. at Sts. 1172 and 1173.

South-east of Cape Town (section 8, Plates XIII–XV), the northward movement in the intermediate layer appears to be very small compared with the northward current in the Atlantic Ocean; the layer has both a small volume and a relatively high salinity. Close to the south coast of the continent the minimum salinity almost disappears; at St. 425 (Station List, 1932) just off the continental shelf south-east of Port Elizabeth the lowest salinity was probably not less than 34·6–34·7 °/₀₀. The only indications of a temperature inversion in section 8 were found at St. 848 in 45° 48′ S, 27° 14′ E.

East of 30° E the properties of the intermediate layer are illustrated by two sections constructed by Möller (1929)—the Ceylon section running approximately north-east from 45° S, 30° E to Ceylon and the Kerguelen section from Gaussberg to the Gulf of Aden. In the southern part of the ocean they are based chiefly on the observations of the 'Valdivia', 'Gauss', and 'Planet'. The salinity distributions along these sections show that the intermediate current is stronger than it is in the region south of Africa, but they also indicate that it has not such a large volume or low salinity as the Atlantic current. The 34·30 °/₀₀ isohaline which extends as far north as 28° S in the intermediate layer in western part of the Atlantic Ocean is found about 8° farther south to the north of Kerguelen. Both the Ceylon and Kerguelen sections indicate that there is a small temperature inversion between the intermediate water and the highly saline deep water in roughly 45 to 25 S°.

The observations along section 9 (Plates XVI–XVIII) south-west of Cape Leeuwin, the south-western extremity of Australia, point to the existence of a current of about the same strength in the eastern part of the ocean; the salinity of the layer is on the whole slightly greater than it is in the Kerguelen section, but the volume of the current appears to be roughly the same, and north of 45° S the increase of salinity towards the north in the current is particularly small.

A section showing the temperature distribution across the Indian Ocean, based on the observations made by the 'Gazelle' between 28 and 38° S, has been published by Möller (1929, fig. 13). Throughout the section from 50 to 110° E there is a very cold layer corresponding to the intermediate layer, with temperatures for the most part less than 3° C. between the surface and warm deep layers. In 102° E the layer has a temperature of less than 2° C., and actually the Gazelle data show that the 2° C. isotherm at a depth of about 1250 m. reaches as far north as 34° S. The occurrence of such a low temperature so far north seems, however, to be quite impossible; even in the western part of the Atlantic Ocean, where our data give every indication of the existence of a stronger current, it is not found north of 46° S. A comparison of Möller's section with section 9 leaves little doubt that the Gazelle data are unreliable. They show that there is a temperature inversion of as much as 3° C. between the intermediate water and the warm deep water, and, as will be proved later, this is most improbable, section 9 showing that there is probably no temperature inversion in the eastern part of the ocean.

The observations in sections 10, 11, and 12 (Plates XIX–XXVII) south of Australia and Tasmania show that the intermediate layer has a very small volume and high salinity. The smallness of the current is probably due in a large degree to the restrictions placed upon it by the presence of such a large land mass to the north, and partly, perhaps, to the fact that a large volume of highly saline water is forced towards the south in the subsurface layer, in order to flow southward of Australia. The northward movement of Antarctic water in the Antarctic Zone itself may also be smaller owing to the relatively low latitude of the shores of the Antarctic continent and the consequent narrowness of the zone. At none of the stations north of the Antarctic convergence was there any indication of a temperature inversion.

South of the eastern half of the Tasman Sea (section 13, Plates XXVIII–XXX) the layer has a slightly greater volume and lesser salinity than south of Australia. The difference is probably due to the northward movement being less restricted, as the highly saline water which flows eastwards south of Australia and southwards in the East Australian current escapes towards the north along the west coast of New Zealand. It may also be due partly to an increased northward movement of Antarctic water, since some of the Ross Sea current finds its way northwards in this region (see pp. 17, 31).

The salinity distribution in section 14 (Plates XXXI–XXXIII) south-east of New Zealand suggests a further increase in the strength of the intermediate current. Wüst (1929, p. 39) shows that the northward movement in this region, combined with the intermediate current in the eastern part of the Tasman Sea, give rise to a poorly saline layer which can be traced as far as 0–16° N, where it mixes with a similar current of Arctic origin.

In the deep basin east of the Antipodes and Chatham Islands, where there are greater movements towards the south in the surface and subsurface strata (see pp. 55, 65), the intermediate current has a greater salinity; but farther east still, in the central part of the ocean, the great volume and low salinity of the layer in sections 15 and 16 (Plates XXXIV–XXXIX) suggest that the current is stronger than it is east of New Zealand. The two sections constructed by Wüst (1929, pls. ii and iv) also suggest that the current is stronger in the central part of the ocean, and Wüst was able to show that the increase of salinity towards the north in the current is remarkably small; between

40 and 20° S it is only 0·03 °/₀₀ compared with 0·18 °/₀₀ in the Atlantic Ocean. The slow rate of increase suggests that the ratio between the movements of poorly saline water towards the north and highly saline water towards the south is more in favour of the northward movement in the Pacific Ocean than it is in the Atlantic.

A preliminary examination of the observations made in the coastal region in the eastern part of the Pacific Ocean suggests that the intermediate current is even stronger. The 34·30 °/₀₀ isohaline reaches as far as 30° S as against 40–45° S in the central part of the Ocean. The salinity distribution in the layer is on the whole in keeping with the conclusion that the intermediate water has a movement towards the east and is deflected northwards in the eastern part of the ocean.

None of our series of observations made south of 41° S in the Pacific Ocean showed the existence of a temperature inversion between the intermediate current and the more saline deep water, but between the 2·5 and 2·25° C. isotherms the temperature depth gradient was only very small, whilst there was a large increase of salinity, and it is very likely that the isotherms mark the boundary region between the intermediate layer and the highly saline deep current. This agrees with the conclusions made by Wüst (1929, p. 30) who found that the observations of H.M.S. 'Challenger' north of 40° S in the central part of the ocean frequently point to the existence of a temperature inversion in the neighbourhood of the 2·25° C. isotherm.

The observations made just north of the Antarctic convergence show that there is generally a secondary temperature minimum at the level of minimum salinity, probably because the sub-Antarctic water contains the greatest percentage of Antarctic water at that level. Below this stratum the temperature increases to a secondary maximum at a depth of about 600 m. According to Sverdrup this warm water flows southwards as a return current into the Antarctic Zone; it has, however, a low salinity compared with the deep water in the Antarctic regions, whose properties suggest that it is chiefly composed of water which climbs from a deeper southward current (see pp. 49, 50, 94, 95). The observations used in making sections 14–18 showed that the temperature at the secondary maximum, just north of the convergence, varied from about 2·8 to 4·2° C., whilst the salinity varied from 34·20 to 34·27 °/₀₀; most of this water probably mixes with the descending Antarctic water and is returned towards the north with the intermediate current.

In the Drake Passage there is generally neither a level of minimum salinity nor one of minimum temperature in the sub-Antarctic water. Their absence suggests that there is only a relatively small volume of Antarctic water sinking at the convergence; and it is reasonable to suppose that the lateral movements, including the sinking of Antarctic water towards the north, are restricted by the narrowness of the passage.

## TEMPERATURE AND SALINITY

Observations made in the Falkland Sector at a point about 100 miles north of the Antarctic convergence (Deacon, 1933, pp. 212–14) show that the temperature of the surface water in the southern part of the zone varies between 3·0–3·5° C. in winter and 6·0° C. in summer. The temperature limits are not quite the same all round the Southern Ocean: where the convergence is far south, as it is in the Pacific Ocean, the sub-Antarctic water is as cold as 2·5° C. in winter and 5·0° C. in summer.

The salinity of the surface water in the Falkland sector was found to vary between 34·10 °/₀₀ at the end of winter and 33·95 °/₀₀ at the end of summer. Elsewhere the data are only sufficient for a very approximate summary. The surface water just north of the convergence in the eastern half of the Atlantic Ocean is usually slightly less saline than that farther west; it varies between about 34·0 and 33·8 °/₀₀. In the Indian Ocean the salinity is still lower—roughly 33·9–33·8 °/₀₀—and it is most likely that the low salinity in this ocean, as well as in the eastern part of the Atlantic Ocean, is due to the large volume of thaw-water which is added to the circumpolar drift by the Weddell Sea current. South of the Pacific Ocean the salinity of the drift increases and it varies between 34·1 and 34·2 °/₀₀ in winter and 34·0 and 34·1 °/₀₀ in summer. The data suggest that there is less movement of thaw-water towards the north in the Pacific Ocean, but a reliable comparison of the conditions in the ocean with those of the opposite sectors cannot be made until the examination of the large number of observations made during the last cruise of the 'Discovery II' (Mackintosh, 1935) has been completed.

Both the temperature and salinity of the sub-Antarctic water increase towards the north, but the properties of the water in the northern part of the zone are not the same in all sectors. Where the movements of the sub-Antarctic and subtropical waters are strongly opposed to each other, as they are south of the Brazil current and south of Africa, the sub-Antarctic water just south of the convergence has a temperature and salinity of only 7–8° C. and 34·3–34·4 °/₀₀. On the other hand, where the convergence is not sharp and the sub-Antarctic current is both farther from its source and mixed to a greater extent with highly saline water, such as is carried southwards by the subsurface current, the temperature of surface water rises to 11·5° C. in winter and 14·5° C. in summer and the salinity rises to 34·9 °/₀₀. These temperature and salinity limits are always an approximate indication of the position of the northern boundary of the sub-Antarctic water; where there is a sharp convergence they coincide with it, and where the sub-Antarctic and subtropical waters have no sharp boundary, they coincide roughly with the position where the temperature and salinity sections suggest that the northward and southward movements are balanced. Where the sub-Antarctic water has been mixed with a southward movement of subtropical water, as frequently happens south of the Brazil and Agulhas currents, the limits seem to give a good indication of the point at which the two waters are mixed in equal proportions.

The temperature and salinity distributions in the subsurface and intermediate currents cannot be given briefly and will most easily be ascertained by reference to the vertical sections. Near the subtropical convergence the properties of the subsurface waters are intermediate between those of the surface water and the subtropical water. Farther south both the temperature and salinity depend on the strength of the southward movement; they are greatest in the region south of Australia, and least in the eastern part of the Atlantic Ocean, the western part of the Indian Ocean, and in the shallow soundings east of New Zealand. Some idea of the salinity distribution in the intermediate current is given by the chart in Fig. 16 as well as by the vertical sections. In the Atlantic and Indian Oceans the isotherms follow the isohalines approximately, and where the low salinity suggests that there is a strong current towards the north, the temperature is also low. This is also true of the Pacific Ocean, but the salinity-temperature relation seems to differ considerably from that of the other oceans, probably because there is no source of highly saline deep water in the northern part of the ocean. The salinity and temperature of the intermediate layer are greatest in the regions south of Australia and south of the Cape of Good Hope, and least in the western half of the Atlantic Ocean and the eastern half of the Pacific Ocean.

## SUBTROPICAL WATER

In the subtropical zone the surface water is much warmer and more saline than sub-Antarctic water, and it can generally be traced to some southward current instead of to a movement towards the north-east. The subtropical convergence, the boundary between the sub-Antarctic and subtropical waters (see pp. 56–63), is the line along which the northward and southward currents reach a balance. The water just north of the convergence has a temperature of at least 11·5° C. in winter and 14·5° C. in summer, but where there is a strong southward movement the temperature may be as much as 5° C. higher, and there is an exceptionally large change of properties from north to south across the convergence; the salinity of the surface water is at least 34·9 °/₀₀, and it may be as much as 35·5 °/₀₀.

In the Southern Ocean the subtropical water has a well-mixed surface stratum, generally with a depth of 60–100 m., but in some localities—near the Cape of Good Hope and off the west coast of Australia—it is found to be almost uniform to as great a depth as 150–200 m. Below the surface stratum, especially in the southern part of the zone, there is frequently a more saline subsurface stratum, in which the southward movement is probably stronger than it is at the surface. The lower salinity of the surface water cannot be due merely to the fact that the surface water retains all the precipitation which falls on the sea, since in this region the dilution from such a cause will probably be more than balanced by the evaporation.

The subsurface stratum is, however, not always more saline than the surface water, and south of Africa and New Zealand it has more frequently the same or a lesser salinity. Theoretical considerations suggest that the southward movement will be stronger in the subsurface stratum when the wind blows from the west so that the southward movement at the surface is retarded. An examination of the data so far available gives some support to this suggestion, but the data are not conclusive.

Below the subtropical water the temperature and salinity both decrease rapidly with depth into the northward Antarctic intermediate current. The depth of the boundary between the northward and southward currents cannot be decided accurately until more information has been obtained about their rates of transport and the eddy viscosity between them; but a preliminary examination of the temperature and salinity sections suggests that the water has a southward component above the 10·5° C. isotherm and the 34·9 °/₀₀ isohaline, both of which are found where the discontinuity between the two layers is sharpest.

## THE MOVEMENTS OF SUBTROPICAL WATER

North of the region of prevailing west winds in the Southern Ocean the winds blow from the south-east or east. They are most regular on the northern side of the subtropical regions of high pressure, which are centred in about 30° S, but near to the land, and especially in summer, they extend farther south. South of Africa the winds alternate, blowing chiefly from the west in winter and from the east in summer and in a narrow coastal region south of Australia there are similar changes. New Zealand lies wholly within the region of west winds, but they are weaker and less constant towards the northern end of North Island, especially in the summer months when the subtropical anticyclones take a more southerly path.

The subtropical convergence—the southern boundary of the subtropical water—has, however, been found to lie some distance to the south of the boundary of the west and east winds, and in the southern part of the zone the wind will cause the surface water to flow towards the east and north. The current charts give ample confirmation of the eastward movement; but the formation of the sharp convergence with the sub-Antarctic water shows that the subtropical water must either flow southwards, or northwards with a smaller velocity than the sub-Antarctic current. It is not unreasonable to suppose that the southward movement of the subtropical water is continued beyond the boundary of the east and west winds; the movement may be partly due to another factor, the thermohaline differences between the Antarctic and subtropical regions; the southward movements set up by the strong east winds which prevail as far north as the equatorial regions must also be strong enough to overrun the northern boundary of the west winds.

In the western part of the Atlantic Ocean subtropical water is carried southwards by the Brazil current. This current has its origin in the trade wind drift and the south equatorial current, which as it approaches the Brazilian coast turns southwards and flows along, or obliquely towards, the land. As far as the River Plate, especially in summer, the southward movement is strengthened by the wind, which has a major component from the north.

Farther south, where the north winds cease, the effect of the earth's rotation and the prevailing west winds tend to destroy the southward movement, and to drive the current away from the land towards the east. In spite of the retarding influences, however, the current continues to force its way 10–15° farther towards the south, and in the temperature and salinity charts of the region it appears as a tongue of warm highly saline water between the cold and poorly saline waters of the Falkland current on the west and the main drift of sub-Antarctic water towards the north-east on the east.

An investigation made by Klaehn (1911, p. 650), based on a very large number of surface temperature observations, shows that the current—still known as the Brazil current—can on the average be traced as far south as 49° S. A close examination of the data shows, however, that the terminal region of the current is one of very irregular movements; the current changes with the wind, and streams of subtropical water alternate, in varying positions, with areas of sub-Antarctic water. Under such conditions there is no fixed boundary between the two waters; their limits appear to be capable of rapid variation, and there are also areas of mixed water. The mean temperature chart shows that water with the temperature which is usually found on the northern side of the subtropical convergence, where it is well defined, reaches an average latitude of 43–44° S.

The subtropical water from the southern end of the Brazil current and the sub-Antarctic water which flows round Cape Horn from the Pacific Ocean, flow together first towards the north-east and then eastwards across the Atlantic Ocean. In spite of the fact that they flow in almost the same direction, the two waters retain to a large extent their distinctive properties, and the rather scanty data available points to the existence of a sharp convergence between them (see pp. 57, 59).

The majority of the Atlantic current charts, probably beginning with that of Petermann (1865), show that the easterly current turns sharply northwards in the eastern half of the ocean, and the Benguela current—the northward current along the west coast of Africa—is represented as a northward branch of the West Wind Drift. The same view was taken in the previous year by Mühry (1864, pp. 34–5), who regarded the low temperature of the water off the west coast of Africa as evidence of the existence of a northward current similar to that which had previously been found off the west coast of South America. The most recent investigation of the surface currents of the Atlantic Ocean made by Meyer (1923) shows very clearly, however, that the Benguela current is not a continuation of the West Wind Drift, but is separated from it by a well-marked convergence. Meyer's chart shows that although the sub-Antarctic part of the eastward current bends towards the north in the eastern half of the ocean, it reaches no farther than 28° S. The temperature and salinity distribution in this part of the ocean (Figs. 8, 11, and Schott, 1926, pl. x) suggests that the northward movement is even less, and there are sufficient data to show that the sub-Antarctic water has a well-defined boundary which does not extend north of 37° S (Fig. 4). The fact that there is a continuous belt of subtropical water across this region, curving southwards from the subtropical region of the Atlantic Ocean to join with that of the Indian Ocean, shows that the older current charts in particular have exaggerated the northward movement of the West Wind Drift.

The temperature and salinity distribution also suggests that some of the subtropical water which flows eastwards across the Atlantic Ocean is possibly deflected southwards near the Cape of Good Hope to mix with the water which turns back from the Agulhas current in an easterly movement across the Indian Ocean. This suggestion finds no support from the current charts of Michaelis (1923) and Meyer (1923), but it is in agreement with the very early chart made by Rennell in 1832. Both Michaelis and Meyer agree, however, with the conclusion first reached by Rennell that some of the water from the Agulhas current flows westwards round Cape Point into the Atlantic Ocean.

There is not sufficient evidence to show that the subtropical water in the eastern part of the Atlantic Ocean actually has a component of movement towards the south, but the existence of a sharp convergence shows at least that its northward component is less than that of the sub-Antarctic water.

In the western part of the Indian Ocean the subtropical water is carried strongly towards the south in the Agulhas current, which flows towards the south-west skirting the African coast. It is caused by the great Trade Wind Drift across the Indian Ocean; as this drift advances towards the African coast it meets the island of Madagascar and divides, one stream flowing towards the northern end of the island and the other towards the south. The first stream, joined by more water from the east, flows round the northern end of the island towards the mainland, where it again divides, part of it turning towards the north and the remainder flowing southwards through the Mozambique Channel towards Natal. The second stream after flowing southward of Madagascar and Mauritius also flows towards Natal, and joining with the southward current from the Mozambique Channel, gives rise to the Agulhas current (Africa Pilot, III, 1929, p. 35). The current is clearly recognizable from 3 to 120 miles off the land, and it generally flows fastest near the edge of the bank. Between Durban and 23° E it attains a velocity of 3–4½ knots, but in its subsequent progress towards the south-west it becomes weaker, and on reaching the Agulhas bank tends to follow the edge of the bank and to branch off to the south. A small portion of the current passes round and over the bank and turns towards the north round the Cape of Good Hope.

Where the main body of the current meets the sub-Antarctic current from the south-west it gives rise to a marked salient of warm highly saline water towards the west in about 40–43° S (see Figs. 4, 8, 11, pp. 19, 29, 45) in which the current curves towards the south and back to the east. The boundary region between the warm and cold currents is a region of irregular movements and confused seas, and there are sudden and irregular changes of temperature and salinity. These changes have already been described briefly on pp. 59, 60, and graphic accounts have been given by Krümmel (1911, II, pp. 673–5), Brennecke (1909, p. 128) and Schott (1902, pp. 130–2). The greater part of the subtropical water appears to turn back near the edge of the Agulhas bank in about 22° E, but sometimes the current has been found to penetrate westwards of 10° E. The surface water at St. 1165 (section 7, Plates X–XII) in 9° 34′ E was undoubtedly subtropical.

The large volume of subtropical water which is turned back towards the east from the Agulhas current is generally known as the Agulhas return current. The temperature and salinity distribution in the Indian Ocean suggest that in addition to its eastward movement it has a small southward component, and the isotherms and isohalines in the neighbourhood of the subtropical convergence show on the whole a small advance towards the south. The presence of so much highly saline water in the surface and subsurface strata as far south as Sts. 869 and 870 in section 9 (Plate XVII) also indicates that the subtropical water tends to force its way southwards.

Most of the older current charts of the Indian Ocean indicate that the West Wind Drift across the ocean divides off Cape Leeuwin, the south-western extremity of the

Australian Continent, sending a branch towards the north along the coast of Western Australia. Krümmel in 1911 (p. 675) regarded the West Australian current as very similar to the Benguela current off the west coast of Africa. Recent work by Michaelis (1923), Schott (1933) and the Hydrographic Office (Australia Pilot, v, 1934) shows, however, that there is no such well-marked northward current. The movements in the coastal region are now known to be weak and variable, with a tendency towards the south in winter and towards the north in summer. Strong currents of 30–40 miles a day have sometimes been recorded, but they are not permanent, and the temperature charts given by Schott (1933, pl. 28) suggest that there is no great transport of water towards the north or south. The temperature charts indicate that the predominating movement during the year, especially very near to the coast, is towards the south.

We made a series of observations across the coastal region between the northern end of section 9 and Fremantle on May 9–10. The temperature and salinity distribution in the first 1000 m. is given in Figs. 17–18. The slope of the isotherms and isohalines shows that there is a southward movement throughout the section, and the lower salinity and higher temperature of the coastal water indicate that it is of tropical origin. At St. 875, roughly 100 miles from the coast, the current was so strong that some difficulty was experienced in handling the ship so as to keep the deep hoists vertical.

The temperature and salinity distribution in the region south-west of Cape Leeuwin shows that a continuous belt of subtropical water extends across the area, just as it does south-west of the Cape of Good Hope, and the West Wind Drift does not divide on the south-western extremity of the continent as many of the earlier charts have indicated. The current charts given by Michaelis (1923), with modifications suggested by the charts of Schott (1933, pl. 28), seem to give the best agreement with the temperature and salinity distributions. The water in the southern part of the subtropical zone flows approximately eastwards, bending slightly northwards in 90–110° E, and then southwards as it approaches the region south of Australia. Farther north the current charts show that the subtropical water is carried northwards in the eastern part of the ocean, principally in summer, to form an anticyclonic circulation such as that which is well known in the subtropical part of the South Atlantic Ocean. The temperature and salinity charts given by Möller (1929, figs. 17, 21) and Schott (1934) give some support for this representation, but the small advance of the isotherms towards the north suggests that the northward movement is probably exaggerated. Willimzik (1929, p. 15) states that in consequence of the northward movement the northern boundary of the West Wind Drift is in winter carried northwards from 36° S in 30–55° E to 25° S in the eastern part of the ocean; but the temperature and salinity charts, especially the latter, give a clear indication that the current does not follow this path. The convergence shown in Möller's charts must therefore not be confused with the boundary between the sub-Antarctic and subtropical waters, which lies much farther south, and it may possibly show the southern limit of tropical water (Deacon, 1933, pp. 216–17).

When the current flows towards the north along the west coast of Australia it is a subtropical current, and it appears to have its origin largely in a movement from the coastal region east of Cape Leeuwin (see Schott, 1933, pl. 28). At all times of the year the current south of North-West Cape has a tendency to set towards the shore, and there is no upwelling of cold water along the coast, such as that which is found off the west coasts of Africa and South America.

At the northern end of section 10 (Plates XIX–XXI), south-east of Cape Leeuwin, the surface water had a temperature of about 21° C. with a salinity of 35·6 °/₀₀, properties which are very similar to those of the southward coastal current found west of Fremantle. Between 37° and 38° 20′ S there was a further body of warm water

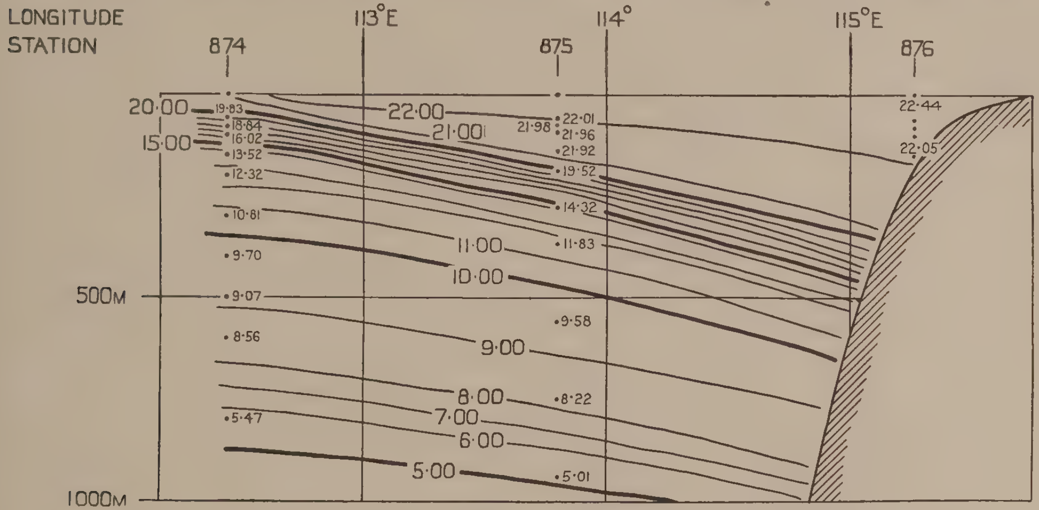


Fig. 17. The vertical distribution of temperature between 0 and 1000 m. along a section extending 185 miles west of Fremantle, West Australia, May 1932.

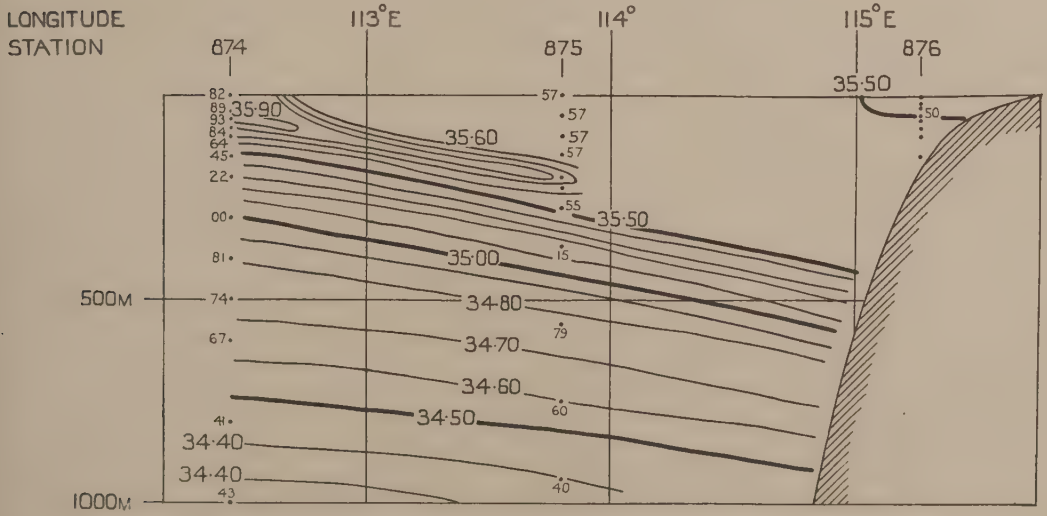


Fig. 18. The vertical distribution of salinity between 0 and 1000 m. along a section extending 185 miles west of Fremantle, West Australia, May 1932.

with a temperature of 18–19° C. and a salinity of 35·8 ‰, which appears to belong to a movement towards the south-east from a region farther offshore in the Indian Ocean. Between 35° 50′ and 37° S the water was colder (15–16° C.), but it still had a salinity of 35·7 ‰ and it was probably part of a current flowing towards the west from the region south of Australia. South of 37° S there was a narrow stream of colder and less saline water whose temperature and salinity, 12–14° C. and 34·9–35·4 ‰ suggest that it probably belonged to an eastward drift in the southern part of the subtropical zone.

South of Australia the current charts of Michaelis (1923) show that the eastward movement extends roughly to 40° S in summer and as far north as a line from Cape Leeuwin to Tasmania in winter. North of these limits the current has a tendency to turn towards the north, and then, forming an anticyclonic movement centred in the western part of the Great Bight, back towards the west. The coastal region is not, however, one with a strong current, and the direction of movement depends largely on the prevailing wind. The current appears to set towards the east for the greater part of the year, but under the influence of easterly winds which occur most frequently in November to April, is reversed (Australian Pilots I, p. 9; and II, p. 27). The current through the Bass Strait between Tasmania and Australia generally flows towards the east, but it may be reversed by an easterly wind.

Off the east coast of Australia there is a southward current of subtropical water, known as the East Australian current, which resembles the Brazil current; it starts as a tropical current, a branch of the equatorial drift towards the west, which turns southwards as it approaches the land. The principal winds off the coast are north-east in summer and south-west in winter, but the current sets almost constantly towards the south. As it flows southwards, into the region of westerly winds, it is gradually deflected to the left like the southern part of the Brazil current. The most recent current chart (a preliminary chart drawn by Merz, published by Wüst, 1929, fig. 10) shows that it is all turned away to the east before it reaches the latitude of the Bass Strait, but our observations in sections 11 and 12 (Plates XXII–XXVII) suggest that it flows farther south. Both the surface and subsurface waters were found to be much warmer and more saline off the east coast of Tasmania than off the west coast, and it seems most probable that the difference is due partly to the continued southward movement of the East Australian current, and also to the bending of the current from the Bass Strait towards the south.

In the eastern half of the Tasman Sea, between Australia and New Zealand, the current flows towards the north-east. Along the west coast of South Island it is mixed with sub-Antarctic water, but most of the mixed water seems to escape towards the east through Cook Strait, and west of North Island the temperature and salinity of the water suggest that it has its origin in the subtropical current from the Bass Strait and East Australian regions. According to Krümmel (1911, II, p. 711) the current bends towards the east round North Cape, and then southwards past East Cape to join, in the neighbourhood of the Chatham Islands, with the currents which flow eastwards from the Cook Strait and round the southern end of South Island. In the southern summer, December to March, the conditions are somewhat different; the north-eastward current in the Tasman Sea is turned back towards the west from Three Kings Islands, and north of New Zealand the current flows west and south. As a result of these changes the isotherms make a marked advance towards the south.

The temperature and salinity distributions east of New Zealand (Figs. 8, 11) show that the water in the relatively shallow soundings between the Chatham and Antipodes Islands and South Island flows principally towards the north, but they also suggest that there is a strong southward movement of subtropical water in the deeper soundings farther east. The surface temperature and salinity charts of Schott and Schu (1910) and Schott (1934) also indicate such a southward movement, but the current chart of Merz (Wüst, 1929, p. 41) for the winter months indicates that it is only weakly developed.

Farther east the current chart suggests that the subtropical water flows principally towards the west and south, having its origin in current branches which turn to the west and south from the Peru current and to the south from the equatorial current. The water movements in the eastern part of the ocean, between 20 and 40° S, are, however, well known only in the coastal region.

The consideration of the meteorological, current, temperature, and salinity charts of the Southern Ocean shows that the subtropical currents flow farther south in summer than in winter, and when sufficient observations are available it will probably be found that the subtropical convergence lies farther south.

In the Atlantic Ocean the greater southward movement of the Brazil current in summer has been established by Klaehn (1911, p. 657 *et seq.*), and the increase in strength can be traced to the fact that the subtropical region of high pressure in the South Atlantic Ocean becomes weaker and less extensive in summer and approaches nearer the African coast. This leads to an increase in the frequency and strength of the north winds off the west coast of Brazil, and to a greater southward movement of the surface water. Farther east in the Atlantic Ocean the data are scanty but they give some indication that the convergence is farther south in summer. They also show that it may make a large advance towards the south which is not part of the seasonal changes (see p. 59).

In the Indian Ocean Michaelis (1923) has shown that in summer the south equatorial current extends farther south and the southern branch of the current which flows round the southern end of Madagascar is stronger. The southward current from the Mozambique Channel is also strengthened in summer owing to the accumulation of water in the Gulf of Zanzibar from the equatorial current and the north-east monsoon drift; and as a result the Agulhas current, which is formed by the union of the two current branches off the coast of Natal, carries a larger volume of subtropical water towards the south-west. The position of the convergence between the subtropical and sub-Antarctic waters in the region south of Africa seems, however, to vary only within limits of 100 to 200 miles and there is no definite evidence of a regular seasonal change. The variation appears to be greatest in the path of the current branch which forces its way westwards into the Atlantic Ocean between 40 and 43° S. Merz (1925, p. 572) from an examination of the surface current charts published by the Meteorological Institute at De Bilt found that the boundary between the Agulhas current and West Wind Drift showed certain variations, but not obvious seasonal changes. The current boundary as shown by his charts does not, however, coincide exactly with the boundary between the subtropical and sub-Antarctic waters, but the absence of changes in its position agrees with the conclusion that the position of the convergence between the two waters has no regular variation.

Elsewhere there are not sufficient data to show whether the subtropical water advances farther south in summer or not, but the greater percentage of easterly winds south of Australia, and the change of the current from east to west together with the advance of the isotherms towards the south in summer north of New Zealand (Krümmel, 1911, pp. 711–12), are indications of such a movement.

### TEMPERATURE AND SALINITY

Just north of the subtropical convergence the water has a temperature of at least 11·5° C. in winter and 14·5° C. in summer, but where there is a strong southward movement the water may be as much as 5° C. warmer. The salinity of the subtropical water just north of the convergence is at least 34·9 °/₀₀, but it may be as much as 35·5 °/₀₀. The surface temperature and salinity both increase towards the north.

In the western part of the Atlantic Ocean it was found that in the neighbourhood of the 23° C. isotherm the gradient became suddenly steeper, and farther north the subtropical water was covered with a shallow layer of water which was found to be practically depleted of nutrient salts and separated from the deeper water by a sharp discontinuity (Deacon, 1933, pp. 216–20). There is sufficient evidence to show that similar water—called tropical water to distinguish it from the subtropical—exists in the Indian and Pacific Oceans. It is carried farthest south in the Brazil, Agulhas, and East Australian currents, but it hardly reaches the limits of the Southern Ocean. South-east of Cape Town, however, we found that between 38° 59′ S, 21° 35′ E and 40° 07′ S, 22° 30′ E the surface temperature was as much as 23·0–23·5° C. in April, and south-east of Cape Leeuwin there was a narrow stream with a temperature of 21° C. in May; the properties of these waters are not very different from those of the tropical water. The regions of high surface temperature are also marked by a high salinity.

The temperature distribution in the subtropical regions is given in the charts constructed for the Atlantic Ocean by Schott (1926, pls. ix, x), for the Indian Ocean by Möller (1929, figs. 17, 21) and for the Pacific Ocean by Schott and Schu (1910, pl. i). The salinity distributions in the three Oceans are given by Schott (1934, pl. i).

## THE WARM DEEP LAYER

One of the most important results of the hydrological work of the circumpolar cruise was the proof that a warm deep layer exists throughout the whole of the Antarctic Zone. The layer and its properties were already well known in the Atlantic Ocean, but in the greater part of the Indian Ocean and in the Pacific Ocean very little was known of them.

The presence of a warm deep layer in the Antarctic region south of the Atlantic Ocean was probably first noted by Powell as long ago as 1821,[1] but it was not until 1922 that Merz and Wüst proved that the layer has its origin in a highly saline current composed of water which sinks from the surface in the subtropical region of the North Atlantic Ocean.[2] They showed that the current has its axis at a depth of about 2000 m. in 10° N and that it flows almost horizontally southwards as far as 40° S, where it rises in a great slope almost to the surface. They called the current the North Atlantic deep current (1922, pp. 22–3).

In the Indian Ocean the observations of Schott (1902) in the 'Valdivia' and Brennecke (1909) in the 'Planet' demonstrate the existence of a warm deep layer, but they are too few to give a clear idea of its properties. Those made by Drygalski (1926) on board the 'Gauss' show that the warm layer has a high salinity, but the salinity measurements are not accurate enough to give a reliable indication of the water movements in the layer. Farther east, south of Australia, and in the Pacific Ocean the data are very scanty. There are a few temperature series made by Captain Scott in the Ross Sea,[3] a few others made in the Bellingshausen Sea during the cruise of the 'Belgica' (Arctowski and Mill, 1908) and a small number of temperature and salinity measurements made in the same region on board the 'Pourquoi Pas?' (Rouch, 1913). More recently observations have been made, principally in the Bellingshausen Sea, by the 'Discovery II' and 'William Scoresby' but in the greater part of the Indian and Pacific sectors of the Southern Ocean the data have so far been too few to allow the properties of the deep water to be described, or to allow its origin to be determined with any certainty.

At the surface in the Antarctic Zone the principal movement of Antarctic water is towards the north; in one or two regions, chiefly in the western part of the Indian Ocean, east of the large cyclonic circulation over the Atlantic Antarctic basin, it may have a small tendency towards the south, but it is evident that such movements can only be small compared with the northward movement found elsewhere. It will also be shown in the following section of the report that there is also a general movement away from the Antarctic continent towards the north in the bottom layer, and since both the surface and bottom currents are found in all sectors of the Southern Ocean they can only exist if there is a compensating movement towards the south in the intermediate deep water.

The properties of the deep water are found to be identical with those which would be expected in a southward movement: the high temperature and salinity alone, occurring as they do between the lower values of the surface and bottom layers, are reliable evidence of a southward movement in the layer. The movement has so far not been confirmed by current measurements, but it has been clearly indicated by the southward drift of several species of plankton.

---

[1] See Marr, 1935, pp. 290–1.

[2] In their review of the theories which have been put forward as to the nature of the circulation in the Atlantic Ocean, Merz and Wüst (1922) point out that the current might have been described sooner on the grounds of the observations made by H.M.S. 'Challenger' in 1873–6, but it was not recognized by Buchanan (Tizard and others, 1885) and Buchan (1895), and the importance of the data was for a time overlooked. The modern representation of the circulation owed its ultimate discovery largely to the comprehensive series of observations made by Brennecke (1921) on the voyage of the 'Deutschland' to the Weddell Sea in 1911–12.

[3] List of oceanic depths, Hydrographic Department, Admiralty, 1904; and *Scott's Last Expedition*, Smith, Elder, and Co. London, 1913.

Since the warm deep layer lies between less saline and colder waters, the temperature and salinity of the deep currents which feed it decrease in the direction of movement, and an increase of salinity or temperature occurring in the path of a current shows that it has been joined by deep water from another source. A chart showing the distributions of salinity and temperature in the layer can therefore be used for an approximate examination of the movements in the layer.

The chart in Fig. 19 shows the distribution of salinity at the level of maximum salinity in the warm deep layer. For the purpose of following the deep currents it is more useful than a chart showing the salinity distribution at one particular depth, since the currents have pronounced vertical as well as horizontal movements, and it is more convenient to use than a large series of charts showing the distribution at small intervals of depth. It is based principally on the data collected by the ships of the Discovery Committee between 1926 and 1934, but it includes some observations made by the 'Deutschland' (Brennecke, 1921) and the 'Norvegia' (Mosby, 1934).

In order to provide a means of checking the conclusions reached from an examination of the salinity chart, others showing the temperature and oxygen content of the water at the level of maximum salinity have also been prepared. In the temperature chart (Fig. 20) the distribution of potential temperature is shown. Where the deep current climbs towards the surface its actual temperature, apart from any changes caused by mixing, will be lowered by the cooling which takes place as the water expands adiabatically and a chart showing the actual temperature could not be used to follow the water movements over a large range of depths, without making some allowance for any change in the depth of the current. A chart showing the potential temperature of the water—the temperature to which the water would be adiabatically cooled if it were raised to the surface—avoids this difficulty.

The oxygen chart in Fig. 21 is not so useful as the salinity and temperature charts because the oxygen content is subject to a greater number of modifying influences; it decreases in the direction of the current owing to the oxygen being used up by the plankton and in various oxidation processes, and also because of mixing with the poorly oxygenated water in the upper stratum of the deep layer; it may on the contrary increase by mixing with the highly oxygenated bottom water. In several regions, however, the chart gives useful confirmation of the deductions made from the salinity and temperature data.

The conclusions reached about the movements in the warm deep layer from the distribution of salinity, temperature, and oxygen shown in Figs. 19–21 do not necessarily apply to the whole of the layer, because the stratum of maximum salinity generally lies in the lower part of the layer. To examine the movements in the warmer upper part

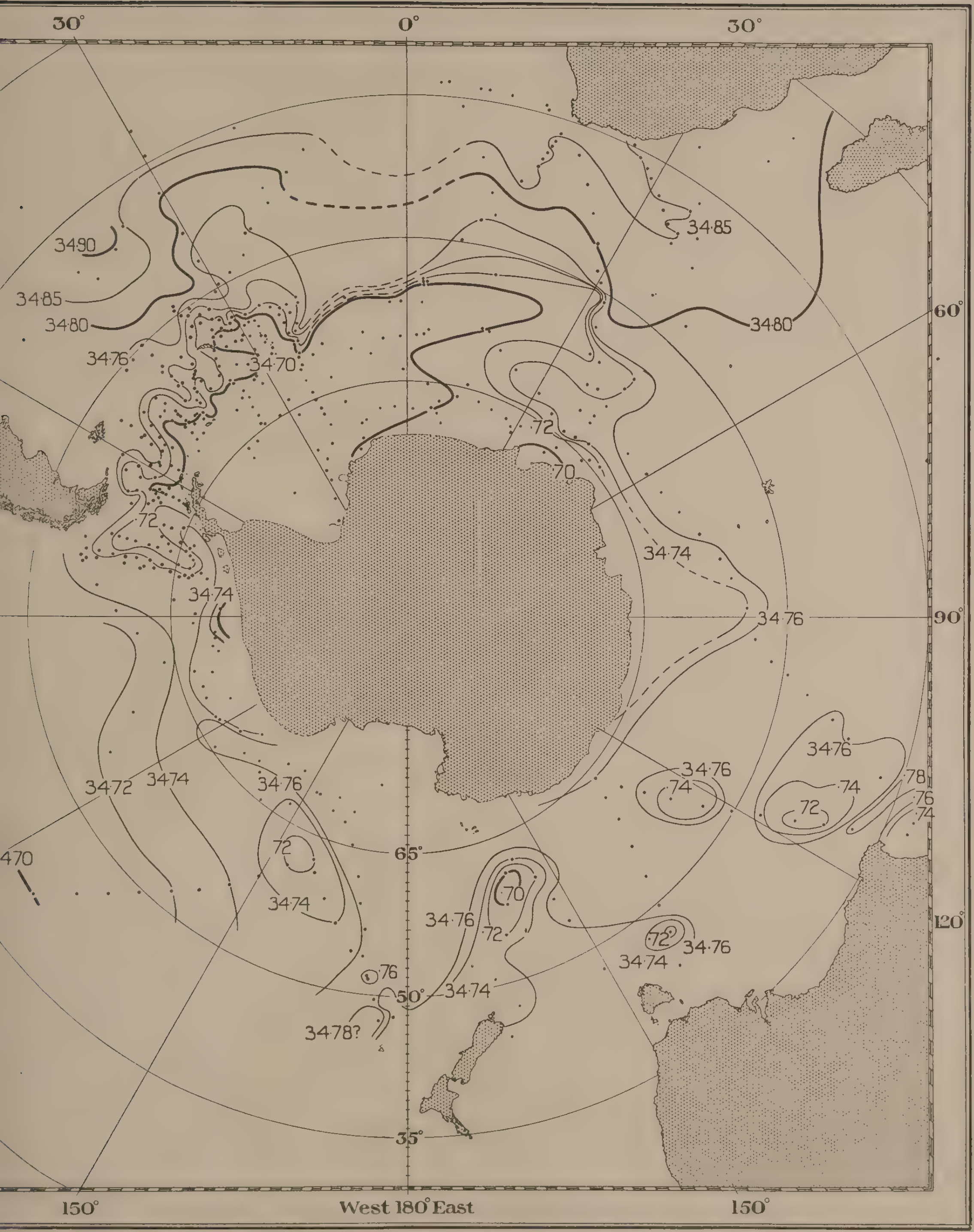

30°
0°
30°
34·90
34·85
34·80
34·76
34·70
34·85
34·80
60°
·72
·70
·72
34·74
34·74
34·76
90°
34·76
34·72
34·74
34·76
·74
·72
·72
·74
·78
·76
·74
470
34·74
34·76
·70
·72
·72
34·76
34·74
120°
65°
50°
34·74
·76
34·78?
35°
150°
West 180° East
150°

Fig. 19. The distribution of salinity at the level of maximum salinity in the warm deep layer.

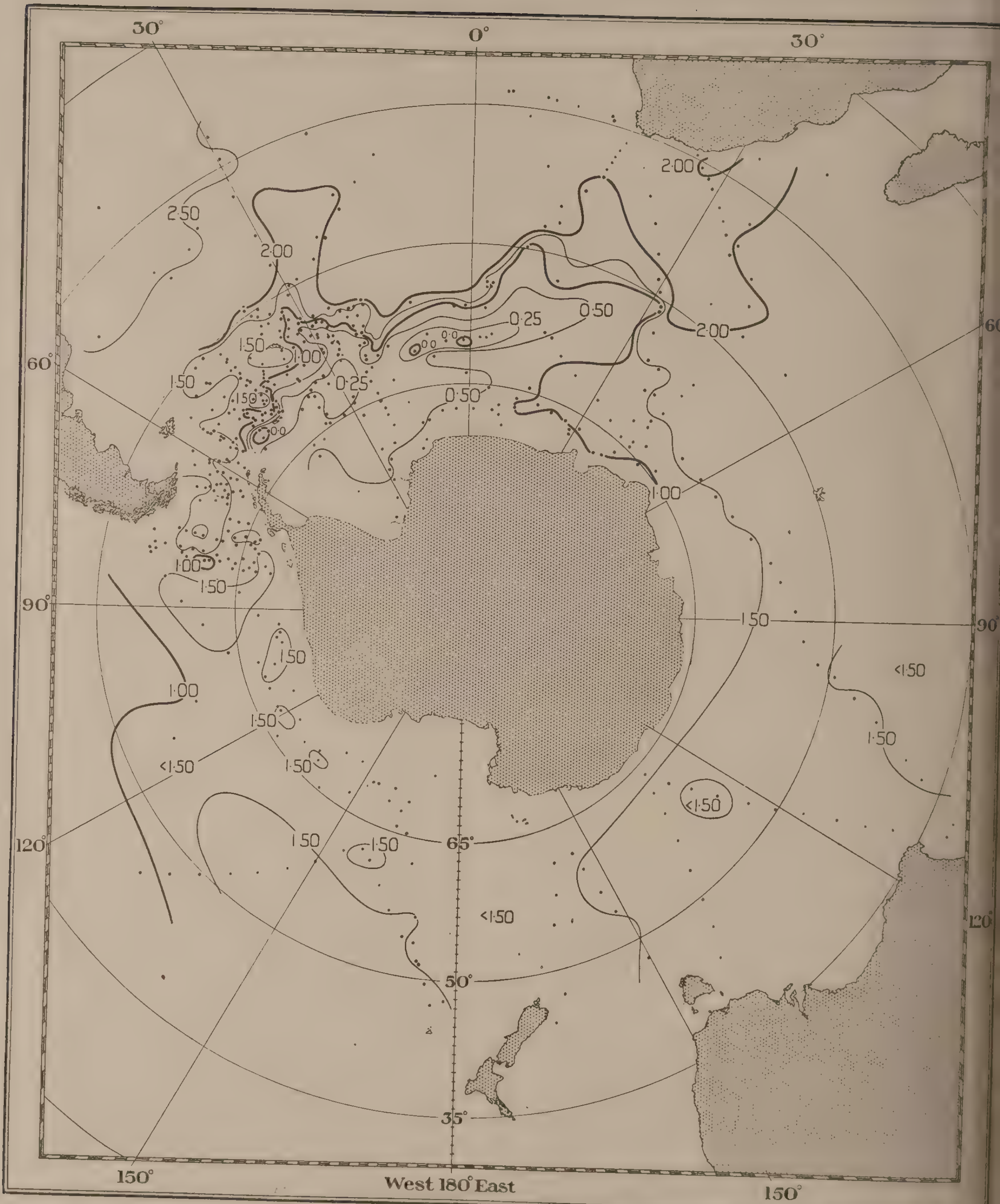

30°
0°
30°
2·50
2·00
2·00
2·00
0·25
0·50
1·50
1·00
60°
1·50
0·25
1·50
0·50
0·0
0·0
0·0
1·00
1·00
1·50
90°
1·50
90°
1·50
<1·50
1·00
1·50
1·50
<1·50
1·50
<1·50
120°
1·50
1·50
65°
<1·50
120°
50°
35°
150°
West 180° East
150°

Fig. 20. The potential temperature of the water at the level of maximum salinity in the warm deep layer.

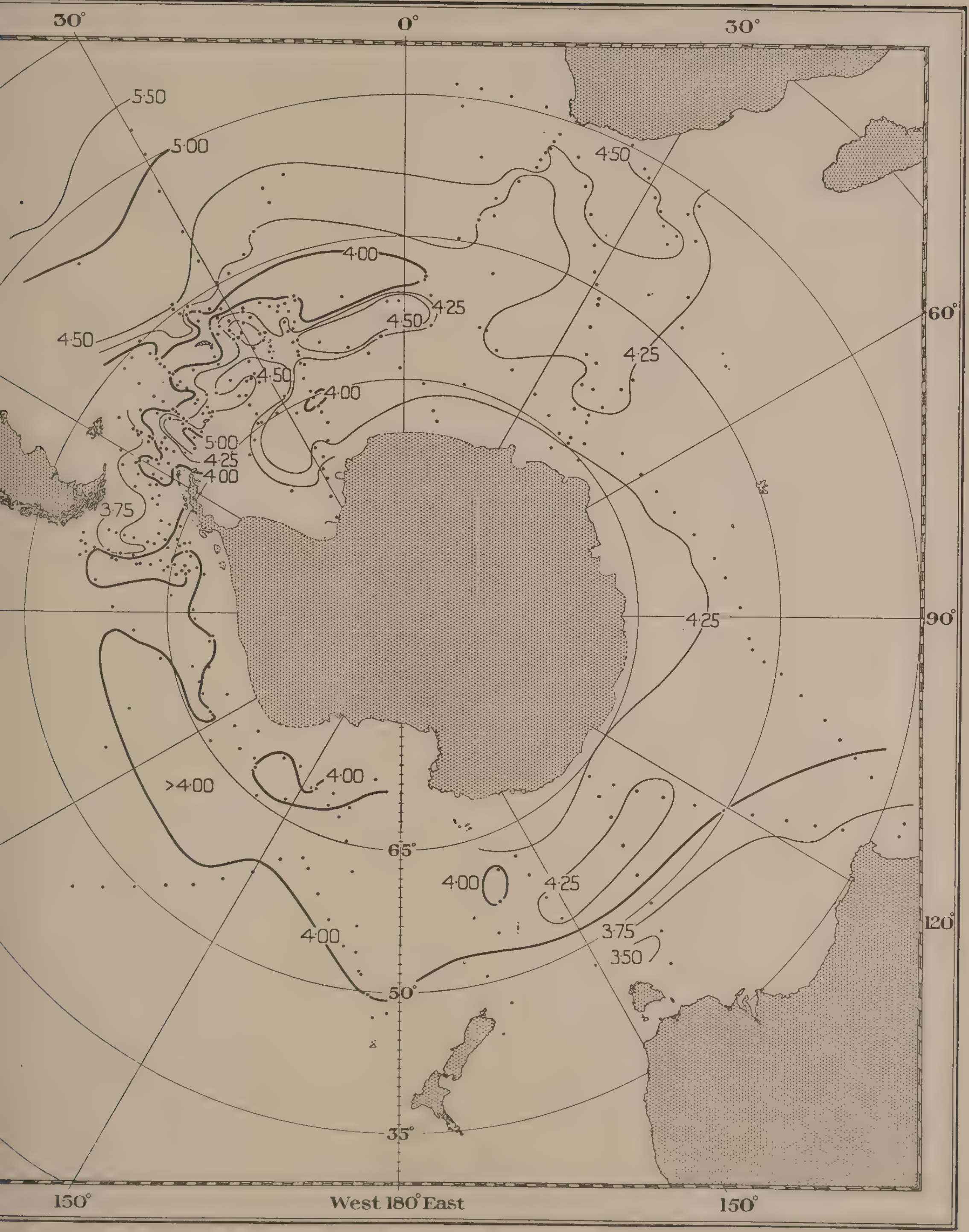

30°
0°
30°
60°
90°
120°
150°
West 180° East
150°
5·50
5·00
4·50
4·00
4·25
4·50
4·25
4·50
4·50
4·00
5·00
4·25
4·00
3·75
4·25
>4·00
4·00
65°
4·00
4·25
3·75
3·50
4·00
50°
35°

Fig. 21. The oxygen content of the water at the level of maximum salinity in the warm deep layer.

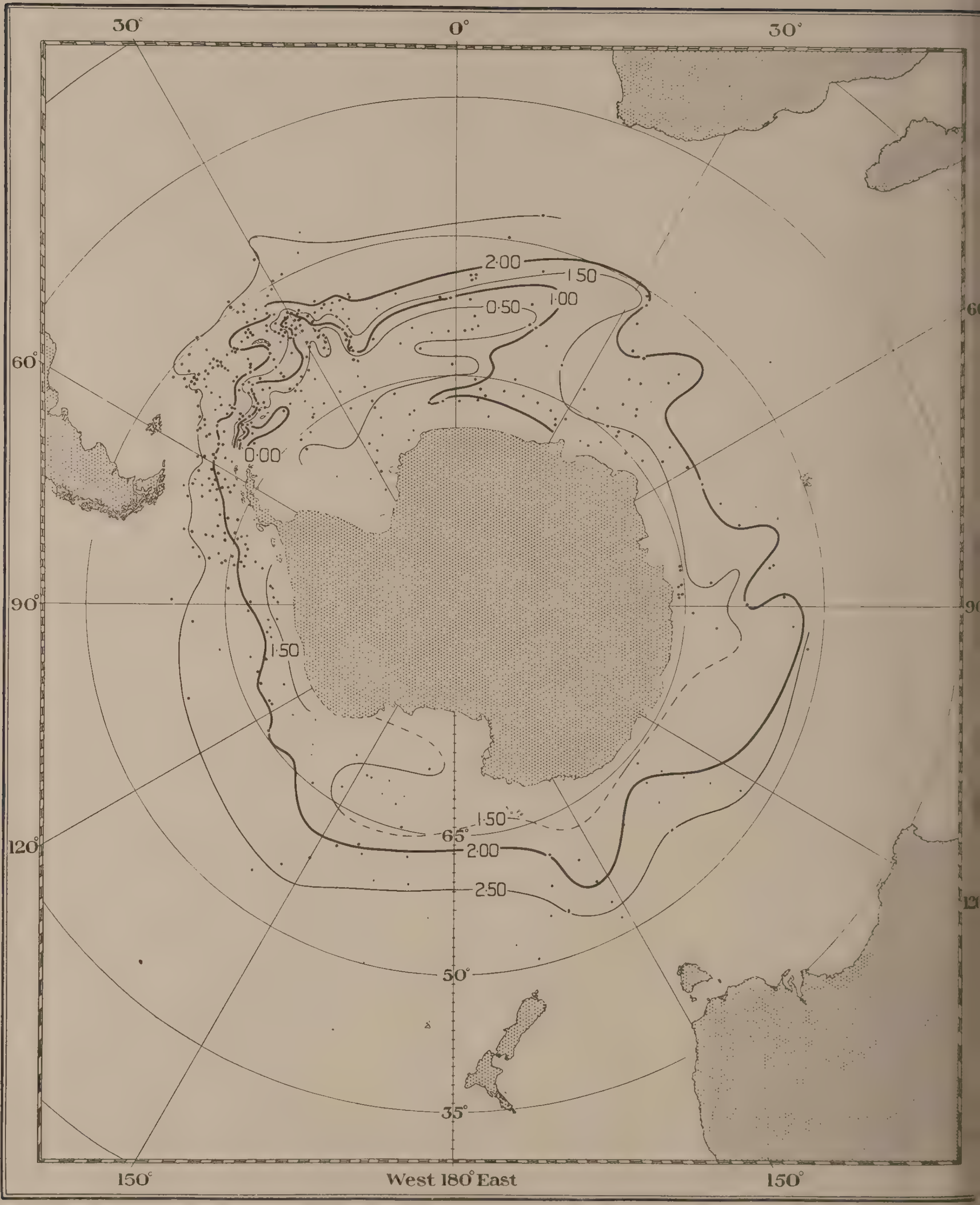

30°
0°
30°
60°
90°
120°
2·00
1·50
1·00
0·50
0·00
1·50
1·50
65°
2·00
2·50
50°
35°
150°
West 180° East
150°

Fig. 22. The distribution of temperature at the level of maximum temperature in the warm deep layer.

Fig. 22 has been prepared showing the temperature distribution at the level of maximum temperature. Since this level can only be distinguished clearly in the Antarctic Zone the chart is confined to that region, and its use is therefore rather limited. In the sub-Antarctic Zone, where the depth interval between the upper part of the layer and the level of maximum salinity is greatest, and the movements in the two strata are most likely to differ, the movements in the upper stratum cannot be examined by such a simple method; they may, however, be determined with reasonable certainty by an examination of the volume and properties of the stratum in the vertical sections. The potential temperature of the water has not been used in Fig. 22 because the variation of the depth of the level of maximum temperature is only small and the temperature corrections to be applied for adiabatic changes are negligible.

In each of the charts showing the properties of the deep layer, data collected during one year or season have been combined with those of other seasons without making any allowance for seasonal or annual changes. These changes are known to be such as cannot be entirely disregarded, but where the observations made in different seasons have fallen close together on the charts the changes have not been found large enough to alter the general shape of the isotherms and isohalines. The changes are greater in a region of steep temperature and salinity gradients than in another where the gradient is small, but owing to the closeness of the iso-lines in such a region the seasonal change shows no great displacement of any of them; the average positions used in the charts are on the whole trustworthy. The seasonal and annual changes of oxygen content were found to be greater, and although they are not large enough to affect the general picture of the distribution, the chart is not so accurate as the temperature and salinity charts. Although the charts are in all probability reasonably accurate the possibility that the distributions may be misrepresented by combining data from different years has been borne in mind. Owing to the great reduction of the charts (from 21·5 × 17·5 in.) it has been found impossible to show all the data, but the points for which figures were available are indicated by dots.

## THE DEEP CURRENTS IN THE SOUTHERN PART OF THE ATLANTIC OCEAN

Merz and Wüst (1922) and Wüst (1928) have shown quite conclusively that the highly saline deep water found in the Argentine Basin, south of the Rio Grande rise and west of the mid-Atlantic ridge (see Plate XLIV), belongs to the North Atlantic deep current, and is water which sinks from the surface in the subtropical region of the North Atlantic Ocean. The distance to which the current penetrates towards the south from the Argentine basin has, however, been somewhat uncertain. Arguing from the sudden fall in the temperature and salinity of the deep water towards the south between 43 and 50° S in 30° W, and from the curving of the contours of the 600 decibar isobaric surface towards this region from the Drake Passage, Clowes (1933) concludes that in 30° W the southward movement of the North Atlantic current comes to an end in 46° S, and he regards the deep water found between this latitude and 55° S as water of Pacific origin.

The facts do not, however, justify this conclusion; the sudden decrease in the temperature and salinity of the current is probably due to the fact that it climbs steeply towards the surface over the colder and less saline Antarctic bottom water; with such a sudden variation of its path the properties of the current are certain to be affected to a marked degree by vertical mixing. It is also not safe to assume that the movement of the deep water will be directed exactly along the line of the contours of the isobaric surface; there is such a close relation where the currents are horizontal and steady, but in the region under discussion, where the vertical movements are pronounced, and the currents are not free from acceleration, the existence of a component of movement towards the south across the contours is not unlikely.

The distribution of temperature, salinity, and oxygen content in sections 4 *a* and 4 (Plates V, VI), north of South Georgia and north-west of the South Sandwich Islands, indicates that the North Atlantic deep current flows at least as far south as South Georgia. The high temperature, salinity, and oxygen content of the deep water at Sts. 1054–6 in 50° S are typical of the North Atlantic current, and water with such a high salinity could have no other origin. The sections also show that the change in the properties of the deep layer between 50° S and South Georgia is no greater than that which may reasonably be regarded as caused by the climbing of the layer, and although some of the deep water may belong to a current from the west, the temperature and salinity distributions give no clear indication of it; there seems to be no water whose properties are appreciably different from those of the Atlantic water. The slope of the isotherms and isohalines downwards to the north is some indication of a current towards the east, but it may, however, be largely the result of the climbing of the deep water to the south and the sinking of the cold surface and bottom waters towards the north. In the neighbourhood of the continental slope north of South Georgia there is a small slope of the isotherms and isohalines downwards to the south which suggests the existence of a small movement towards the west.

The observations in section 4, north-west of the South Sandwich Islands, indicate that the North Atlantic deep current climbs towards the south as far as 52–53° S without interruption; its last traces may reach a still higher latitude, but the rapid decrease of temperature, increase of oxygen content and the changes of salinity south of 53° S suggest that the deep water belongs chiefly to a current from another source. The properties of this water are such as might result from the mixing of the North Atlantic water with Antarctic bottom water, but the charts in Figs. 19–22 suggest that it belongs to a current flowing from the southern and eastern parts of the Scotia Sea.

The temperature and salinity distribution in the deep layer in the western part of the Scotia Sea shows that the current flows mainly east and south, but in the eastern part the deep water appears to follow the curve of the Scotia Arc, turning towards the north to flow out of the sea as a cold deep current. The temperature and salinity distribution in sections 4 and 4 *a* shows that some of it sinks into the bottom layer below the North Atlantic current, but the charts in Figs. 19–22 indicate that it also turns towards the east round the northern end of the South Sandwich group. It then eddies back to the south in the South Sandwich deep before continuing eastwards across the Atlantic Ocean. It will be shown in a later part of the report that the water in the northward movement probably contains water from the deep currents of both the Atlantic and Pacific Oceans, and its low temperature and salinity and high oxygen content show that these waters are mixed with a large proportion of the cold deep and bottom waters of the Weddell Sea.

The observations in section 6 (Plates VIII, IX) indicate that the northward movement is strongest at St. 1140, very near the South Sandwich Islands and the southward movement at St. 1142 in 20° 31′ W in the eastern half of the South Sandwich deep. Section 5 (Plates VII, IX), a longitudinal section in the eastern part of the deep, also shows that there is a strong southward movement; at St. 806 in $57\frac{1}{2}°$ S the water between 800 and 1000 m. has a salinity of as much as 34·76–34·75 $°/_{oo}$, and it must be largely Atlantic water. The deep water at St. 808 also has a relatively high salinity and temperature, and it seems that the Atlantic water reaches as far as 60° S.

Between St. 806 and 808 the deep water has a lower temperature and salinity, and a higher oxygen content, and the data in the section suggest that there is a sharp cyclonic current eddy in which the relatively cold deep water belonging to the northward current along the Scotia Arc is carried eastwards into a region where the Atlantic water might otherwise flow southwards without interruption. The eddy appears to be a permanent feature of the water movements in this region; it is shown in a section constructed by Mosby (1934, fig. 14), affecting the conditions at Norvegia St. 48 between St. WS 555 (Station List, 1932) and 'Vikingen' Sts. 1 and 2 (Ruud, 1930); it is probably caused by the influence of some irregularity of the bottom topography which has not yet been discovered.

Sections 5 and 6 both show that the temperature of the warm deep water decreases suddenly towards the south in about 60° S, and between the warm deep water found north of this latitude and a further warm region near the Antarctic Continent, the deep water is so cold that it can only belong to an eastward movement of deep and bottom waters from the Weddell Sea. Against this cold current, which cannot contain any appreciable volume of Atlantic water, the southward movement of the North Atlantic deep water comes to an abrupt end. The data available are sufficient to show that the cold current is continuous towards the east as far as 30° E, but it is not certain that the Atlantic current throughout the whole of this distance has such a sharp termination as it has east of the South Sandwich Islands. The sudden difference of temperature in the deep layer between Sts. 460 and 461 (Station List, 1932), and the abrupt change of salinity between St. 453 (*ibid.*) and Norvegia Sts. 1–3 (Mosby, 1934) show, however, that there is probably a sharp boundary lying a short distance south of Bouvet Island. The observations in section 7 (Plates X–XII), in about 15° E, are too far apart to show whether the Atlantic current has a sharp termination; the deep water at St. 1160, however, seems to be plainly Atlantic water, whilst that at St. 1158 belongs to the eastward current from the Weddell Sea, and the section suggests that the Atlantic water reaches as far as 55–56° S.[1]

---

[1] The origin of the deep water at St. 1147 (section 6) in 61° 50′ S, 8° 10′ W, is not quite certain, but on the whole the data suggest that it belongs to the warm deep current found near the Antarctic Continent (see p. 93).

The conclusion reached from all the observations made in the eastern half of the Atlantic Ocean is that the North Atlantic deep current does not flow farther south than 60° S near the South Sandwich Islands and 56° S in the meridian of Cape Town; in the region immediately south of these latitudes the deep water is so cold that it can only be water which flows eastwards from the Weddell Sea, or upwelling bottom water, and there is no evidence of a strong eastward movement from the Pacific Ocean such as Clowes (1933) and Sverdrup (1933, p. 166) have suggested. The high temperature and salinity of the deep water at Sts. 806 and 808 in $57\frac{1}{2}$ and 60° S, in section 5, and the low temperature and salinity at St. 809 in 61° 10′ S show that there is very little space between water which is unmistakably of North Atlantic origin and water which can only come from the Weddell Sea.

In the Indian Ocean, the warm deep current flows as far south as the continental slope of Antarctica without encountering such obstruction from an eastward movement as that which it meets in the Atlantic Ocean. In the neighbourhood of the slope it bends towards the west into the Atlantic Ocean, where it is found as a warm current to the south of the cold current which flows eastwards from the Weddell Sea.

The southward movement in the western part of the Indian Ocean is partly formed of North Atlantic water, but it also appears to contain water from a similar origin in the northern part of the Indian Ocean. By means of a section along 60° E, Schott (1926) showed that there is a North Indian deep current formed by the sinking of highly saline surface water from the Arabian Sea and the Red Sea. The existence of the current was confirmed by a comprehensive examination of all the data available from the ocean by Möller (1929). In the subtropical region the data were very scanty, but in the absence of a greater number it seemed almost certain that the deep water which fills the western part of the ocean, between the latitude of the Cape of Good Hope and the Atlantic-Indian cross-ridge, with a salinity of as much as 34·80 °/₀₀, was a southward continuation of the North Indian deep current.

Observations made since 1929 in the subtropical part of the ocean have, however, suggested that the highly saline deep water in the southern part of the ocean does not belong to the north Indian deep current. Thomsen (1933) has used the observations of the Snellius and Dana expeditions to show that the North Indian deep current does not have a salinity as great as 34·80 °/₀₀ south of a line from the northern end of Madagascar to Ceylon. Further light has been thrown on the question by a series of observations made by the 'Discovery II' along a line from Marion Island through the Mozambique Channel to the Gulf of Aden. A preliminary examination of the data (Clowes and Deacon, 1935), shows that the highly saline water from the northern part of the Indian Ocean has a salinity of 34·80 °/₀₀ as far south as 20° S in the Mozambique Channel, but although the current probably continues towards the south with a lesser salinity, it is clearly not the source of the water with a salinity of 34·80 °/₀₀ found in the western part of the ocean as far as 50° S. This water has the same or a higher salinity than the north Indian water in 20° S, but it is as much as 2° C. colder and 2 cc. per litre richer in oxygen. It is also separated from the highly saline water of the north Indian deep current by a stratum of slightly lesser salinity. Its properties, and the horizontal distribution of salinity, temperature and oxygen content in the deep water south of Africa (Figs. 19–21), show that it belongs to an eastward movement of North Atlantic deep water. In the light of these new observations it is clear that the Mozambique section constructed by Möller (1929, figs. 4–5), though based on fewer data south of the equator, points to the same conclusions. Möller does not regard the highly saline water at the southern end of the section as essentially Atlantic water, but realizes that it may be derived partly from such an origin. The existence of an eastward current from the Atlantic Ocean was first suggested by Merz and Wüst (1922, p. 23) from the temperature chart for the depth of 1500 fathoms given by Buchan (1895, map 13) in the Challenger reports. Wüst also notes the existence of the current in a preliminary account of the Meteor results (1926, p. 250); these results suggest that the salinity of the deep water increases towards the south in the region south of Africa, and Wüst supposes that the Atlantic water flows eastwards chiefly south of 40° S, outside the region influenced by the Agulhas current. Our observations (in section 8, Plate XIV, and Fig. 19) show, however, that the greatest salinities are found very near the land and indicate that the Atlantic current flows eastwards close round the Cape of Good Hope. The level of the maximum salinity is below the deepest observations on which Wüst bases his preliminary assumption that the deep layer in the region of the Agulhas current has a low salinity (Meteor Sts. 135–7, Wüst, Böhnecke, and Meyer, 1932, p. 96).

There are not sufficient data to show how far the Atlantic water penetrates towards the east across the Indian Ocean; but the temperature, salinity and oxygen distribution in the region south-east of the Cape of Good Hope suggest that a large part of the current bends towards the south between 30 and 40° E. The low oxygen content of the water east of 40° E is probably a reliable indication of the presence of deep water from the north Indian current. A preliminary examination of the observations made by the 'Discovery II' along the line from Marion Island to Socotra (referred to above) supports this conclusion. Although the deep water south of 20° S belongs partly to an eastward movement from the Atlantic Ocean it is not safe to assume that the southward movement of the north Indian deep current has come to a sudden termination; the low oxygen content of the upper stratum of the warm deep layer south of 20° S suggests that the Indian water continues towards the south above the Atlantic water, and the other properties of the layer are in close agreement.

In the neighbourhood of the Antarctic Continent the isotherms and isohalines bend towards the west, and a tongue of warm highly saline water extends along the shores of the Antarctic Continent as far as the Weddell Sea. Brennecke (1921, pp. 117 and 124), who first noted a rise in temperature of the deep water towards the south in the southern part of the Weddell Sea, regarded it as an indication of a westward movement from the Indian Ocean, where the observations of the Valdivia expedition had already shown that the deep water had a relatively high temperature within a short distance of Enderby Land. In Brennecke's time it was too early to trace the origin of the current farther back than this, but our data suggest that the current is composed partly of North

Atlantic deep water which enters the Indian Ocean between the Cape of Good Hope and 56° S and partly of north Indian deep water.

The salinity, temperature, and oxygen distribution in the Atlantic-Antarctic basin as a whole, points to the existence of a large cyclonic circulation in the deep layer similar to that which has already been described at the surface. The north Atlantic water which flows eastwards into the Indian Ocean and is joined by north Indian water, turns first southwards, then westwards along the edge of the Antarctic Continent and northwards along the east coast of Graham Land, and finally back to the east along the northern side of the basin. As it flows along this path the temperature and salinity of the current decrease continuously owing to mixing with the colder and less saline surface and bottom waters.

Section 8 (Plates XIII–XV) crosses the cyclonic circulation near its eastern end, and the high salinity of the deep water close to the continent (34·74–34·75 °/₀₀ in 59–64° S) shows that the deep water finds a much easier path towards the south in this region than it does farther west. At Sts. 850 and 851 there are, however, still some indications that the current is interrupted by eddies of colder water from the west. The temperature and salinity observations at St. 850 point to the existence of a particularly active eddy: the evidence which the section gives may perhaps be slightly exaggerated, since the observations at Sts. 1551–2, which have been included in the section to bridge the large gap between Sts. 850 and 851, were made in a different year. It is also possible that the eddy is not a part of the major cyclonic circulation of the Atlantic-Antarctic basin, and it may be entirely or partly a local movement caused by the deep water flowing over the very uneven bottom in this region. The bottom topography is not well known, but it has been found to be very irregular, and the soundings change as much as 2000–3000 m. over very short distances. The distribution of temperature in the bottom layer (see pp. 112, 113, and Plate XLIV) indicates that an S-shaped ridge connects the southern part of the mid-Atlantic ridge with the Marion Island-Crozet Islands ridge, and such a ridge might be the sole cause of the eddy. A second and weaker eddy was found at St. 851 in 56° 22′ S, 37° 22′ E, and the salinity, temperature and oxygen charts in Figs. 19–22 suggest that it marks the eastern end of the cyclonic movement; farther east the warm deep water appears to flow southwards without interruption.

The deep current towards the west along the continental slope south of the Atlantic Ocean has at first a width of about 500 miles; the isotherms and isohalines in Figs. 19–22 suggest that all the deep water south of 60–62° S in the region between 15 and 5° E, flows towards the west. In 2–4° E the current divides on the Maud Bank, on which Isachsen (1934, p. 161) found a sounding of only 1200 m. in 65° S, 2° 35′ E: a longitudinal section drawn by Mosby (1934, figs. 17–19) in 5° E, based on the Meteor data (Wüst, 1928, pls. xxxiii, xxxiv) and the Norvegia data, shows that the warm water at the Meteor St. 130 in 64° S is separated from the main body of the westward current farther south by a region of colder water. Mosby (p. 38) suggests that the indication of the splitting of the current was only a misrepresentation of the actual conditions, brought about by combining data from different years, but he probably was not aware of the existence of the Maud Bank, which is not shown in his sections. Section 6 (Plates VIII, IX) passes over the eastern end of the bank in 65° S, 4° E, and the warm water at St. 1147 probably belongs to a branch of the westward current which flows north of the bank.

Section 5 (Plates VII, IX) crosses the eastern part of the Weddell Sea, between 21 and 23° W. In this region the westward current is clearly defined only south of 67° S; in the central part of the sea between 61 and 67° S the variations in the temperature, salinity, and oxygen content of the deep layer, and the undulations of the isotherms and isohalines suggest that both the surface and deep currents are weak and variable. Earlier sections made across the same region by Brennecke (1921, pls. 4–6) and Mosby (1934, figs. 14–16) have given the impression that the currents are much more regular; they have suggested that there is only a steady movement towards the west in the southern part of the sea and towards the east in the northern part, the strength of each current decreasing gradually to a narrow boundary region in the middle of the sea. Both sections were, however, based on a much smaller number of observations than section 5, and it is probable that more data would have revealed the same irregularities that we have found.

Each of the sections across the region shows how the situation of the central part of the sea in a divergence region between the currents towards the west, farther south, and towards the east, farther north, is marked by the upwelling of bottom water. Our observations further emphasize the fact that the divergence region is wider in the Weddell Sea than it is in the eastern half of the Atlantic Ocean. Such a difference and the existence of the irregular movements in the central part of the Weddell Sea may be caused by the falling away of the coast-line towards the south-west; the expanding of the westward currents in both the surface and deep layers into a wider space in the Weddell Sea may be supposed to make them less regular and more susceptible to wind changes.

Brennecke's observations in the western part of the sea show that the isotherms and isohalines bend towards the north along the east coast of Graham Land and back towards the east in the northern part of the sea. The deep current must follow the same path, becoming continuously colder and less saline as it mixes with the surface and bottom waters. The Deutschland observations in the southern part of the Weddell Sea show that in 27½° W the current had a temperature of as much as 0·79° C., but in 44° W it was only 0·66° C., and in Nordenskjöld's section across the northward current in about 65° S (1917, pl. 2) not more than 0·4° C. In the northern part of the sea and across the northern part of the Atlantic-Antarctic basin the warm deep layer is also weakly developed; its maximum temperature over a very extensive region (see Fig. 22) is not more than 0·5° C., and its maximum salinity not more than 34·66–34·69 °/₀₀. At St. 638 (Station List, 1932) between the South Shetland Islands and the South Orkney Islands the maximum temperature and salinity in the deep layer were found to be not more than − 0·19° C. and 34·60 °/₀₀; the great weakness of the current in this region seems to be caused by the sinking of surface water in a convergence region between the water flowing northwards out of the Weddell Sea and the more easterly drift farther north (see pp. 108, 109).

The temperature, salinity, and density or specific volume sections across the region of low temperature in the deep layer (sections 5–7; Brennecke, 1921, pls. 4–6; and Mosby, 1934, figs. 11–18) show that the low temperature and salinity of the water are due partly to the upwelling of cold and poorly saline bottom water, but they also suggest that the deep current which flows northwards along the east coast of Graham Land and eastwards in the northern part of the Weddell Sea, mixed with the upwelling bottom water, continues eastwards across the Atlantic Ocean as far as 30° E. As it flows eastwards, particularly in the eastern half of the Atlantic Ocean, the current diminishes in volume, and its temperature and salinity increase: the vertical sections across it and the charts in Figs. 19–22 indicate that the diminution is caused by its gradual sinking towards the north below the Atlantic water, and especially in the terminal region of the current, by mixing with the Atlantic and Indian deep waters.

The conclusions drawn so far with regard to the movements of the deep water apply chiefly to the more saline deeper part of the layer; the water in the warmer less saline upper part of the layer may have somewhat different movements. Sverdrup (1933) has suggested that the water in this part of the layer in the Antarctic Zone is formed just north of the Antarctic convergence by the mixing of the water which sinks from the Antarctic surface current with the highly saline deep water, and the current arrows which he has drawn in his sections (figs. 3–23) show that he regards the Antarctic water as the greater component of the mixture. Sverdrup's conclusions were, however, drawn chiefly from an examination of the temperature sections, and it seems to me that insufficient weight given to the evidence of the salinity distribution, which he himself recognized as showing a different picture (1933, pp. 150–1), has made him exaggerate the importance of the Antarctic contribution to the southward movement.

The vertical distribution of salinity north of the Antarctic convergence (see Fig. 13, p. 47) suggests that most of the Antarctic water which leaves the surface continues towards the north, but Sverdrup regards the bending of the isotherms back towards the south round the end of the cold stratum of the Antarctic layer in the temperature section (Fig. 12) as an indication that the surface water bends back towards the south to feed the warmest stratum of the deep layer. The relatively high salinity of the water, even at this level, seems, however, to prove that it contains more water from a southward movement such as the North Atlantic deep current, than surface water. Such a conclusion also explains the temperature distribution; the high temperature of the water at the level of maximum temperature is just as likely to be the result of a southward movement in the deep layer as it is to be caused by the sinking of surface water. The small variation in the properties of the upper stratum of the warm deep layer from summer to winter is an argument in favour of this conclusion. The question of seasonal changes in the deep water has not yet been closely examined, but a comparison of the data obtained in winter at Sts. WS 251–310 (Station List, 1930) with observations made in the same region in summer, shows that the upper part of the layer is not appreciably colder in winter. If a large part of the Antarctic water turned back to the south in the upper part of the warm deep layer, from a point just north of the convergence, a large seasonal change would be expected.

Although the salinity of the warm water in the upper part of the deep current is much greater than that of the Antarctic surface water, it is about 0·1–0·3 °/₀₀ less than that of the main body of the southward deep current—the North Atlantic deep current in the Atlantic Ocean—from which it is derived, and it must therefore contain some Antarctic water. According to my interpretation of the data the dilution of the highly saline deep water takes place chiefly in the southern part of the subtropical regions, and in the sub-Antarctic Zone, but it is also brought about gradually throughout the whole length of the southern Atlantic, Indian and Pacific Oceans as the Antarctic intermediate currents flow northwards above the more saline southward currents in the deep layer. In the Atlantic Ocean (Deacon, 1933, pls. vii and viii) the less saline stratum of the deep layer is formed by the mixing between the Antarctic intermediate current and the North Atlantic deep current; the exact boundary between the two currents is not yet known, but it must lie in the discontinuity stratum between the two layers, and, even in the tropical and subtropical regions, some of the water whose salinity is 0·1–0·3 °/₀₀ less than that of the main body of the Atlantic current must have a southward movement. The spreading of the isohalines between the intermediate and deep currents in the Argentine basin south of 35° S points, however, to the existence of a region of intense vertical mixing between them and indicates that the warmer and poorly saline stratum of the warm deep water is formed chiefly in this region.

The return of Antarctic water towards the south in the deep current must be largely responsible for the maintenance of the concentrations of nutrient salts at such a high level in the Antarctic Zone. The north Atlantic deep current is itself not as rich in phosphate as the warm deep water in the Antarctic Zone, and for the greater part it has not more than 80 mg. $P_2O_5$ per m.$^3$ (see Deacon, 1933, pl. viii). The water containing most phosphate (140–160 mg. $P_2O_5$ per m.$^3$) is found between the Antarctic intermediate current and the warm deep current south of 35° S, principally in 38–43° S. The presence of so much phosphate in this locality, which is also a region of low oxygen content, suggests that it is liberated by the decomposition of plankton carried northwards in the Antarctic current. The mixing between the northward and southward currents and probably a continuation of the decomposition in the southward current, causes a large proportion of the phosphate which leaves the Antarctic regions to be carried back again. It is not yet clear why the whole water column in the Antarctic regions is so rich in phosphate compared with the deep and bottom waters in other parts of the world, but such a cycle as that described above, and the extensive zonal movements in the surface, deep, and bottom layers, are likely to play a large part in maintaining the high concentration. The nitrate distribution in 30° W (Deacon, 1933, pl. ix) points to the existence of a similar cycle of nitrogen content.

In the Antarctic Zone, there is not a great depth interval between the levels of maximum temperature and salinity in the warm deep layer, and the movements in the upper part of the layer are probably very similar to those in the lower and more saline part. The temperature distribution at the level of maximum temperature supports this conclusion; there is plainly the same cyclonic circulation in the Atlantic-Antarctic basin, and the southward movement of the North Atlantic deep water seems to end in about 60° S east of the South Sandwich Islands and in 56° S south of Cape Town.

The salinity, temperature, and oxygen distribution in the subtropical region of the South Atlantic Ocean and south-east of the Cape of Good Hope in the Indian Ocean shows that the North Atlantic deep water spreads towards the east as well as to the south, but so far it has not been found possible to compare the strengths of the two movements. The southward movement is probably caused by the demand for a current to compensate the northward movements in the intermediate and bottom layers, and the greater strength of these northward movements in the western half of the ocean is reasonably supposed by Wüst (1928, p. 531) to account for the greater strength of the North Atlantic deep current in the western Atlantic basin (see Fig. 19, and Wüst, 1926, pp. 237–42). The effect of the earth's rotation alone would cause the current to be most strongly developed in the eastern half of the ocean.

The bending of the isotherms and isohalines towards the north in the region adjoining 30° W (see Figs. 19, 20) suggests that the southward movement of deep water is weaker than it is farther west. The region is situated at the northern end of the deep channel from the Atlantic-Antarctic basin to the Argentine basin (see Plate XLIV), and the smaller southward movement is probably due to the influence of the stronger northward bottom current.

## THE DEEP CURRENTS IN THE SOUTHERN PART OF THE INDIAN OCEAN

A brief description of the north Indian deep current, which Schott (1926), Möller (1929), and Thomsen (1933) have shown to be formed by the sinking of highly saline surface water in the Arabian Sea and adjoining gulfs, has already been given (pp. 90, 91). The properties of the current, high salinity and temperature, and low oxygen content are well known, but the distance to which it penetrates towards the south is still rather uncertain. Möller (1933) regards the existing data as sufficient to show that it spreads southwards as far as the Antarctic regions, even though Thomsen (1933) had shown that the Dana observations along a line from the northern end of Madagascar to Ceylon suggested that such a current might not exist south of the equator. A preliminary examination of the data collected by the 'Discovery II' along a line from Marion Island to Socotra through the Mozambique Channel (Clowes and Deacon, 1935) shows that although the most saline water in the deep layer south of 20° S belongs partly to an eastward current from the Atlantic Ocean, the less saline water in the upper part of the layer is probably derived largely from the north Indian deep current. In 20° S the southward movement of the current appears to be partly obstructed by the northward movement of Antarctic intermediate water, which lies at a much greater depth south of 20° S than in the northern part of the ocean; but the oxygen section in particular suggests that the current continues towards the south below the intermediate water and above the Atlantic water. A comparison of Möller's longitudinal sections (1929, figs. 4, 5, 8, 9), based on the observations of the 'Valdivia' and 'Ormonde', with the section given by Thomsen (1933, fig. 3) based on the data obtained by the 'Planet', 'Snellius' and 'Dana', suggests that the volume and salinity of the north Indian deep current are subject to large variations, probably related to the changes of salinity in the coastal regions, and to the current differences brought about by the changes of the monsoon winds, and variations in the south equatorial current. Another indication that the deep water circulation of the ocean may undergo large changes is pointed out by Möller (1933, p. 235); in the equatorial region of the eastern part of the ocean the 'Snellius' found that the Antarctic intermediate current was strongly developed with a salinity of less than 34·6 °/₀₀, but at the Dana stations 5° farther north there was no sign of it. Möller suggests that unless this difference can be shown to be the result of some hitherto unknown morphological feature south or south-west of the Bay of Bengal, it must be regarded as evidence of a great fluctuation of the deep water circulation.

The observations made by the 'Snellius' and 'Dana' also show that no deep current comparable with that which flows from the Arabian Sea and its adjoining gulfs is formed in the north-eastern part of the ocean (Möller, 1933, p. 234), and the salinity distribution in the cross-section from west to east across the ocean in 8° N to 2° S shows that the deep water formed in the western part of the ocean spreads towards the east.

The existing data are still insufficient to show the exact part played by the Atlantic deep current in the Indian Ocean. The high salinity and oxygen content in the south-western part of the ocean (Figs. 19, 21) suggest that the lower strata of the deep water are largely of Atlantic origin, but the decrease of salinity and oxygen content towards the east indicates that east of 40° E the layer may contain a large proportion of water from the north Indian deep current. It is, however, probable that some of the Atlantic water finds its way right across the ocean. The observations of the 'Dana' and 'Snellius' so far published indicate that the deep water found at St. 878 (section 10, Plates XIX–XXI), about 200 miles south-east of Cape Leeuwin, the south-western extremity of Australia, with a salinity of as much as 34·78 °/₀₀, is too saline to have its origin entirely in the north Indian current, and suggest that it belongs chiefly to an eastward movement of Atlantic water. It is, however, not quite safe to draw such a conclusion at present; in view of the possibility that there are large fluctuations in the deep water circulation of the ocean, the data from the north-western area are too scanty to give final information about the salinity of the north Indian deep current.

In the Southern Ocean, the need for a compensating current towards the south in the deep layer, and the influence of the prevailing west wind may be supposed to cause the deep water to flow south and east. The data obtained along sections 8 and 9 (Plates XIII–XVIII) support this conclusion. The southward movement is probably strongest in the eastern part of the Atlantic-Antarctic basin, between 50° E and the Kerguelen-Gaussberg ridge (see Figs. 19–22, section 9, and Plate XLIV), and again south of Australia. East of the Kerguelen-Gaussberg ridge (Sts. 861–4, section 9) the southward movement appears to be weaker, whilst the northward movement in the bottom layer is stronger. The increase in the strength of the bottom current and the decrease in that of the deep current are probably due to the influence of the shallow soundings in the neighbourhood of the ridge on the eastward movement in both layers (cf. Ekman, 1928). The greater northward tendency appears to prevail too far to the east of the ridge in section 9, but it must be remembered that the ridge runs almost south-east, and also that there is another extensive area of shallow water a short distance farther east in the neighbourhood of the Shackleton ice-shelf.

The observations made south of 32° S in the sub-Antarctic and subtropical zones in the eastern half of the Indian Ocean show that the deep water has for the most part a maximum salinity of 34·75–34·76 °/₀₀, and is throughout less saline, colder, and poorer in oxygen than the deep water of the same salinity farther west. These properties suggest that it is formed partly by the mixing of the north Indian deep water with the colder and less saline Antarctic bottom water, and the poorly saline though warmer water of the intermediate current; but there is also good reason to believe that it contains water which flows eastwards from the Atlantic Ocean. The upper part of the layer has a particularly low oxygen content which, although it may be due partly to the lack of a rapid circulation in the eastern part of the ocean, also suggests that the water belongs to the north Indian current.

From a temperature section across the ocean in 34° S based chiefly on the observations of the 'Gazelle' (1874–6), Möller (1929, fig. 13, pp. 26, 37–8) concluded that the deep layer was reinforced in the eastern part of the ocean by a second deep current, similar to the north Indian current, formed along the north-eastern seaboard. In a more recent paper, however (1933, p. 234), written after the salinity measurements of the 'Dana' and 'Snellius' were in part available, she was able to show that there was no such current, and that the evidence of the Gazelle section is evidently misleading. Our observations suggest that the section is based on faulty data. The mean of the observations at Gazelle Sts. 82, 83 shows that the water in 34° S, 102° E has a minimum temperature of 1·9° C. at a depth of 1250 m.; but such water could only be Antarctic surface water near the convergence, or Antarctic bottom water. The second of these possibilities is ruled out because the water is found at such a shallow depth, above warmer water, and the first could only be realized if there was a much stronger northward movement of Antarctic water in this region than there is even in the western half of the Atlantic Ocean, an occurrence which is definitely contradicted by the observations in section 9, and by the surface temperature charts compiled from other sources (Möller, 1929, figs. 17, 21). The Gazelle data also show that below the cold water, between 1500 and 2000 m., there is a stratum whose maximum temperature is as much as 3° C. higher, and the existence of such a large inversion seems to be almost impossible: our observations farther south showed no sign of an inversion, and if the deep water in 34° S were so much warmer than the water at 1250 m. it would probably have to be more saline than any deep water found in the Indian Ocean in order to make the water column stable.

The salinity, temperature, and oxygen distribution in the Southern Ocean south of Australia (Figs. 19–22, sections 10–12, Plates XIX–XXVII) indicates that the deep water flows principally towards the east and south. The southward movement is probably a compensation current to balance the northward movements of Antarctic water, and the eastward movement may be due to the prevailing west wind, to density differences between the two oceans, and perhaps to the need for an eastward current to balance the movement towards the west through the Malay Archipelago. The temperature and salinity distribution gives some indication that the eastward movement is strongest in the deep channel near Cape Leeuwin (Plate XLIV and section 10), where the deep water has a salinity of 34·78 °/₀₀. The next highest salinities were found in the central part of section 11, south-west of Tasmania, and the salinity distribution suggests that the current flows eastwards across the Great Bight, bending southwards as it reaches the shallow water west and south of Tasmania.

South of the deep channel the easterly movement seems to be weaker; the low salinity and high temperature of the deep water, and the sinking of the isotherms and isohalines between 41 and 45° S in section 10, suggest that the deep layer is diluted by the sinking of water in the centre of an anticyclonic eddy in the eastward movement. The reason for the existence of the eddy cannot be given with certainty, but its situation, over the western end of the South Australian basin, suggests that it may be caused by the influence of the sharp changes of depth on the eastward current. There is a second region of low salinity in the deep current between 53 and 56° south, but in this instance the salinity and temperature are both lowered by the upwelling of bottom water, probably in the centre of a cyclonic eddy, whose situation over the eastern end of the Australian Antarctic basin shows that it too may be a consequence of the influence of the bottom topography on the eastward current.

The observations in the neighbourhood of Tasmania give little indication of the existence of a southward movement of deep water in the western half of the Tasman Sea; the low oxygen content of the water north of 45° S in sections 12 and 13 (Plates XXV–XXX) might be the result of such a movement, but it is plain that the current, if it exists, has no marked effect on the temperature and salinity distributions.

## THE DEEP CURRENTS IN THE SOUTHERN PART OF THE PACIFIC OCEAN

The deep water circulation of the Pacific Ocean has been known for some time to differ considerably from that of the Atlantic and Indian Oceans, but so few observations have been made in the deep and bottom layers of the ocean that the conclusions reached have been largely hypothetical. Wüst (1929) showed that the Arctic intermediate current—the current analogous to the Antarctic intermediate current but having its origin in the surface currents of the Arctic regions—is not rudimentary as it is in the Atlantic Ocean, but is a strong current which flows southwards until it meets the Antarctic current near the equator, and in consequence the highly saline surface waters of the subtropical regions are almost entirely separated from the deep and bottom waters by a poorly saline layer of intermediate water, and are not able to sink into the deep layer as the surface water in the North Atlantic Ocean does.

A careful examination of all the data available, principally observations made by the

'Challenger' and 'Planet' gave Wüst reason to suppose, however, that the separation of the surface and deep waters was not quite complete, and he suggested that in 0–9° N, in the central part of the ocean between the two intermediate currents, the conditions were such that a limited volume of surface water was able to sink in order to form a highly saline deep current, similar to the North Atlantic deep current, though with not such a high salinity. Although there were not enough data to establish the existence of a highly saline deep layer very definitely Wüst was able to find good reasons for supposing that it existed.

The northward movement in the Antarctic intermediate and bottom layers is itself an almost certain indication that there must be a southward compensating current in the deep layer. Wüst also found (1929, p. 46) that the Challenger observations in the central part of the ocean frequently showed that in the neighbourhood of the 2·25° C. isotherm, between 1500 and 2000 m., the temperature increased slightly with depth, and suggested a stratification in which colder intermediate water lay above warmer southward-flowing deep water. The range of the temperature difference was actually found to be not outside the possible limits of error of the Challenger observations, but even the existence of a weak temperature gradient instead of an actual inversion seems to be sufficient to justify Wüst's conclusions. It was also most significant that the salinity was found to increase with depth below the level of the intermediate current, and south of 30° N in the western part of the ocean, the high salinities measured by the 'Planet', 34·70–34·72 °/₀₀ and in one instance 34·79 °/₀₀ (St. 55, 15° 42′ S, 165° 44′ E) clearly point to the existence of some kind of highly saline current.

Wüst recognizes the possibility of other highly saline currents than that which might be formed by the sinking of surface water in the region between the intermediate currents in the central part of the ocean. He suggested that a small volume of highly saline deep water may be formed in some of the more or less enclosed basins found in the equatorial regions. The Planet St. 55 (Reichard, 1911) was made about 270 miles north of an outlet of the Fiji basin. There is also a possibility that some of the highly saline surface and subsurface waters may break through the poorly saline intermediate layer at some point near the coast of Australia between 30 and 35° S, and finally he shows that there may be a deep current from the Indian Ocean into the Pacific Ocean south of Australia; according to Möller (1929) it was safe to assume that such a current would have a salinity of more than 34·70 °/₀₀.

After an examination of the Carnegie data of 1928–9, Sverdrup (1931) concluded that the deep water circulation of the Pacific Ocean was not only quantitatively different from the circulations of the Atlantic and Indian Oceans but also of a different character. In the region examined (approximately 40° S to 50° N, north-east of a line from 40° S, 100° W to the Fiji Islands and Japan), the deep water below 2000 m. was found to be very uniform, with a salinity of 34·64–34·67 °/₀₀, and Sverdrup regards the longitudinal section through the western part of the ocean drawn by Wüst (1929, pls. i. ii) and the Carnegie data from the central part of the ocean as sufficient evidence that this water cannot be formed by the sinking of surface water in the equatorial region. He also rejects a possibility of its being formed in the Antarctic regions because its temperature (presumably for water whose salinity had been raised to 34·64 °/₀₀ by freezing processes) is too high, and concludes that it belongs to an eastward current from the Atlantic and Indian Antarctic Oceans, especially the latter, which enters the Pacific Ocean south of Australia. The existence of an eastward movement had previously been suggested by Defant (1928, p. 491), Wüst (1929, p. 48) and Möller (1929, pp. 37–8), but it assumed a new significance when Sverdrup had shown that there was no sinking of surface water in the equatorial regions.

Our data, collected during the circumpolar cruise, have been used in the construction of sections 14–18 (Plates XXXI–XLII) and the charts in Figs. 19–22, the latter are also based on the preliminary examination of observations made during cruises across the ocean south of 65° S in 1934 (see Mackintosh, 1935, p. 629). A few of these observations have also been used to continue sections 14, 16 and 18 towards the south.

Except in the western part of the ocean and in the extreme eastern part near the western end of the Drake Passage, the most saline deep water is found in the southern part of the Antarctic Zone, the salinity being actually greatest in about 65° S. The temperature, salinity, and oxygen content of this highly saline water are plainly very similar to those of the deep water found south of Australia, and very different from those of the deep water found farther north in the Pacific Ocean itself, and they suggest that the current has its origin chiefly in an eastward current from the Indian Ocean. Tracing the history of the water farther back, it must be regarded as north Indian deep water and North Atlantic deep water, both waters having been considerably modified during their progress towards the south and east by mixing with the Antarctic surface and bottom waters.

In spite of the fact that the greater part of the most saline deep water appears to belong to the eastward current from the Indian Ocean there are some indications that there may be a second though smaller source of highly saline deep water in the western part of the ocean north of New Zealand. The observations made during the circumpolar cruise suggest that the deep water east of New Zealand has a slightly higher salinity than the eastward movement which enters the ocean south of New Zealand. The water actually had a salinity of not more than 34·75 °/₀₀, which, together with its temperature and oxygen content, suggests that it belongs to the same current as the deep water south of Australia; but the observations south of the Tasman Sea indicate that the two waters, east of New Zealand and south of Australia, are separated by an extensive area in which the deep water has a slightly lesser salinity. Between New Zealand and 61° S in section 13 the salinity of the deep water is not more than 34·74 °/₀₀, and between Tasmania and the same latitude, in section 12, it is for the most part less than 34·75 °/₀₀. A close examination of the hydrological conditions in this region supports the conclusion that the salinity of the water found south of Australia should be reduced as it flows towards the east. The bottom topography south of New Zealand is so irregular that the eastward current must be interrupted by numerous eddy movements which will cause the salinity to be lowered by turbulent mixing with the less saline waters in the shallower and deeper strata. The deep channel between the new Zealand shelf, which extends as far south as the Campbell and Auckland Islands, and the Antarctic shelf, is less than 1000 miles wide, and it is obstructed by several shallow banks and islands. A preliminary examination of our soundings along sections 12 and 13 suggests that the bottom topography is even more rugged than has hitherto been supposed.

Further observations made east of New Zealand in the deeper soundings to the east of section 14 (Sts. 1277–81, Appendix I) showed that the salinity of the deep water may be as much as 34·78 °/₀₀, but no simultaneous observations were made in the region south of Australia. The data as a whole are not conclusive, but they give a weak indication that water east of New Zealand is slightly more saline than that which enters the Pacific Ocean south of New Zealand. Before the difference can have much significance, however, it must be confirmed, and more information must be obtained of the possible fluctuations in the salinity of the eastward current due to changes in the deep water circulation of the Indian Ocean (see p. 97), but its likelihood suggests that there is still a possibility of a small highly saline current from another source, such as one of those suggested by Wüst—sinking of the surface water in some partly enclosed basin in the subtropical regions, or in the coastal region east of the northern part of Australia. The salinity, temperature, and oxygen distributions in section 14 suggest that the principal movement in the highly saline stratum east of New Zealand is towards the north, but they do not preclude the possibility of a small southward movement of highly saline water with a low oxygen content in the upper part of the highly saline stratum.

The data from the southern part of the Pacific Ocean as a whole (sections 14–18) suggest that the highly saline water in the Antarctic Zone spreads towards the east, and also, as a bottom current, towards the north. Above this bottom current and below the northward current in the intermediate layer there is, however, evidence of a stratum of deep water whose high temperature and low oxygen content, combined with a salinity greater than that of the intermediate water, suggest that it flows southwards; its movement appears to be almost horizontal until it approaches the Antarctic Zone where it climbs towards the surface, steeply in the west and gradually in the east; it then flows almost horizontally again, in the upper stratum of the deep layer, as far as the continental slope. The properties of the water in the current suggest that it is formed chiefly in the equatorial region by the mixing of the highly saline water carried northwards by the bottom current with the warmer but less saline waters of the Arctic and Antarctic intermediate currents. The difference between its properties and those of the intermediate and bottom waters is the strongest indication that it flows southwards, and the signs of a temperature inversion between the intermediate water and the deep water found by Wüst (see p. 100), and the need for a compensation current to balance the northward movements in the intermediate and bottom layers are good arguments in favour of the same movement.

The high temperature of the deep water in the eastern part of the Antarctic Zone and the increase in the temperature of the deep layer towards the east from the region south-east of New Zealand (see p. 104) shows that the eastward current from the region south of Australia must be joined by warm water from another source—most probably from a southward movement in the upper stratum of the layer, such as that which has been described. The decrease of salinity and oxygen content, which the sections show to accompany the increase in temperature towards the east, also suggests that the current is modified by the addition of less saline and poorly oxygenated deep water from the north. .

The southward movement in the upper stratum of the deep layer in the Antarctic Zone may partly be the cause of the most saline water being confined to such a narrow zone; although the deeper part of the highly saline current sinks towards the north the upper part appears to have a southward movement, and some of the highly saline water which sinks towards the north is probably carried back with the southward current.

The intermediate, deep and bottom currents are not separated by any well-marked boundaries. Our observations, made entirely south of 40° S, showed no indication of a temperature inversion such as that found by Wüst to the north of this latitude; but the relatively small temperature gradient between the 2·25 and 2·5° C. isotherms, with the accompanying sharp salinity gradient, suggests that they mark the boundary region between the intermediate and deep currents. The boundary between the deep and bottom currents is especially vague, and there is probably extensive vertical mixing between them. The oxygen distribution in section 15 (Plate XXXVI) suggests that a large part of the current which flows southwards between 1500 and 2500 m. north of 50° S sinks between 50 and 55° S to mix with the bottom water; this means that a large part of the southward movement does not make the climb to the higher level of the current in the Antarctic Zone but returns directly towards the north with the bottom current. The depression of the isotherms and isohalines in 50–55° S points to the same conclusion, but it may be caused partly by a difference in the zonal movements.

Since the water in the southward movement between the intermediate and bottom currents is formed in the Pacific Ocean, and, by analogy with the current systems in the Atlantic and Indian Oceans, it seems that the southward current should be called the Pacific deep current. It must, however, be remembered that the deep current is not more saline than the bottom current, as in the Atlantic and Indian Oceans, but on the contrary less saline.

A most striking feature of the conditions along section 14 (Plates XXXI–XXXIII) is the low salinity of the deep water between 60 and 65° S, where the data point to the existence of a sharp cyclonic eddy caused by the passage of the eastward deep current over the Cape Adare-Easter Islands ridge. Another point worthy of note is that the observations made farther south suggest that south of 70° S, along the northern side of the Ross Sea, the current flows towards the west; together with the salinity and temperature charts in Figs. 19, 22, the observations indicate that there is a small cyclonic circulation of the deep water in this region resembling in a slight degree that found in the Atlantic-Antarctic basin.

The temperature distributions in sections 16–18 (Plates XXXVII–XLII) show that the warm deep water flows more strongly towards the south in the eastern half of the ocean than in the western half. In 100° W the current has a temperature of 2° C. as far as 70° S, whereas in section 14, north of the Ross Sea, such a temperature was not found south of 61–62° S; the lower salinity of the deep water also points to an increase of the strength of the southward movement in relation to the eastward current from the Indian and Atlantic Oceans. A comparison of the observations made at St. WS 502, at the southern end of section 17, with those made at St. 1245, at the southern end of section 16, suggest that the equilibrium between the eastward and southward currents is subject to some variations. The former observations, made in January 1930, show that the deep water between 69 and 70° S had a salinity of as much as 34·76 °/₀₀, whilst those at St. 1245, made in January 1934, showed no greater salinity than 34·72 °/₀₀. The temperatures measured at the latter station were, however, slightly greater than those found at St. WS 502, and together with the salinity data they suggest that the equilibrium between the southward and eastward movements was more favourable to the southward movement in 1934 than in 1930: the current difference between the two years is apparently not very large because the 34·76 °/₀₀ isohaline reached to within 400 miles of St. 1245 in 1934.

The distribution of salinity, temperature and oxygen content in the most saline stratum of the deep layer in the south-eastern part of the ocean (Figs. 19–21) indicates that the highly saline current from the Indian and Atlantic Oceans is turned towards the north as it approaches the western end of the Drake Passage. Between 80 and 90° W the deep water in 55° S has properties similar to those which are only found in 65° S across the greater part of the ocean farther west. The northward movement appears to bring about a large reduction in the volume of the deep water flowing towards the east, and in spite of some indications to the contrary it seems that not more than a comparatively small volume of the Indian and Atlantic waters which form the eastward current can enter the Atlantic Ocean through the Drake Passage.

The strongest indication of an eastward movement of the deep water through the passage is the slope of the layers of equal density downwards to the north, and using such evidence Wüst (1926, pp. 243–4) concluded that the Pacific deep water influences the whole of the Scotia Sea; Clowes (1933) believes the current to be even stronger and supposes that it flows eastwards across the Atlantic Ocean; in 30° W he places the northern boundary of the current in 46° S. This conclusion was, however, based largely on the assumption that the deep-water movements followed the contours of the isobaric surfaces exactly, and in this region where in addition to the eastward movement there are currents which sink towards the north, climb towards the south, and are not free from acceleration, the assumption is probably not justified. An examination of the temperature and salinity distribution north of South Georgia and north-west of the South Sandwich Islands (see p. 88) indicates that the North Atlantic deep water approaches to within a short distance of South Georgia, and these observations, together with others made farther east (see p. 90), show that there is no definite indication of the presence of a Pacific deep current in the Atlantic Ocean outside the Scotia Sea.

The deep-water transport between the Pacific and Atlantic Oceans is also likely to be restricted by the narrowness of the passage between the continental shelves of South America and Antarctica: in section 1, between Elephant Island and the Burdwood Bank, the deep channel is not more than 360 miles wide. The further progress of the eastward current is also likely to be hindered by the Scotia Arc, the well-defined submarine connection between the Andes of South America and the mountains of Graham Land through South Georgia, the South Sandwich Islands and the South Orkney Islands (Herdman, 1932, pp. 214–19, and Wilckens, 1933, pp. 320–35). The deep water of the Scotia Sea is probably, as Wüst (1926) suggests, largely of Pacific origin; but owing to the great similarity between the deep waters found in the eastern part of the Pacific Ocean and the terminal region of the North Atlantic deep current, the composition of the deep water in the boundary region between the two oceans cannot as yet be determined with any certainty.

The salinity measurements made up to the present (see Fig. 19) show that the deep water in the middle part of the western end of the Drake Passage generally has a low salinity, less than 34·72 °/₀₀, and although the salinity is greater along the northern and southern sides of the passage it seems likely that no large volume of water with a salinity of as much as 34·74 °/₀₀ flows eastwards from the Pacific Ocean to the Atlantic. There is, however, a large area at the eastern end of the passage, from 50 to 54° S in 50–60° W and extending 4–5° farther south in 57–59° W, in which the deep water has a salinity of 34·74–34·75 °/₀₀, and the existence of such an area suggests that the deep layer at the eastern end of the strait contains some North Atlantic deep water. Such a possibility is strengthened by the fact that the water has a potential temperature 0·25–0·5° C. higher than that of the highly saline water at the western end of the strait. The conclusion that Atlantic deep water approaches as far as the eastern end of the passage is, however, put forward with some hesitation, since it is based on small temperature and salinity differences. The conclusion is also based largely on data which have been collected over a large number of years with no allowance for seasonal and annual changes, but it is nevertheless justified on the grounds of the data illustrated in sections 17, 18, 19, and 1, which were obtained for the most part within the space of a few weeks. The maximum salinity of the deep layer in section 18 across the western end of the passage varied between 34·72 and 34·74 °/₀₀, with a potential temperature of 0·8–1·5° C., whilst that in section 1 across the eastern end varied between 34·74 and 34·75 °/₀₀ with a potential temperature of 1·2–1·9° C.

The observations made at the eastern end of the Drake Passage show that the deep water has a smaller oxygen content than it has at the western end (see Fig. 21); the most saline water in section 1 had an oxygen content of 3·5–4·1 cc. per litre, whilst that in section 18 had as much as 3·8–4·3 cc. per litre. Since the deep water in the Atlantic Ocean has been found to have a much higher oxygen content where its salinity was high enough to show that it must be of North Atlantic origin (cf. St. 1055, section 4, 2000 m.), the low oxygen content at the eastern end of the Drake Passage seems to point to the absence of Atlantic water. It may, however, be supposed that the Atlantic water will have a low oxygen content in the terminal region of the North Atlantic current. The deep water at St. 1019 (section 1), north of the Scotia Arc and near the Falkland Islands, had a salinity of 34·75 °/₀₀; it seems most likely to be North Atlantic water, and its oxygen content at the level of maximum salinity was only 3·51 cc. per litre. The fact that the oxygen content of the deep water increases both towards the south-west and north-east from the eastern end of the passage is in accordance with the assumption that the region is a terminal region between the Atlantic and Pacific deep currents.

The deep water in the Scotia Sea appears to be a most comprehensive mixture of waters, which can be traced back to the Atlantic, Indian and Pacific Oceans. It is probably derived largely from the eastward movement in the Pacific Ocean and is therefore likely to contain Indian and Atlantic Ocean waters which have found their way more than half round the Antarctic Continent towards the east, as well as the less saline water which flows southwards in the Pacific Ocean. It also appears to contain Atlantic water from a direct southward movement over the northern arm of the Scotia Arc, and in the lower part of the layer, Weddell Sea deep water which has been formed from a westward movement of Atlantic and Indian deep waters along the Antarctic slope. The composition of the less saline upper part of the layer is even less certain than that of the deeper part, and the Atlantic and Pacific waters cannot as yet be distinguished. The temperature sections indicate, however, that there must be a southward movement in the layer to maintain the large temperature difference between the deep water and the surface and bottom waters in the Antarctic Zone, and it seems likely that such a movement will bring Atlantic water into the Scotia Sea.

The observations made across the sub-Antarctic Zone in the Pacific Ocean suggest that the volume of Antarctic intermediate water carried back towards the south in the upper part of the warm deep current is exceptionally large; within a narrow zone extending about 100 miles north of the convergence there is a well-defined temperature inversion between the level of minimum salinity, where the sub-Antarctic water contains the greatest percentage of Antarctic water, and the more saline deeper layer, where the water which may be supposed to flow southwards. It is not, however, safe to assume that all the water at the level of maximum temperature in the deep water north of the convergence finds its way into the upper part of the warm deep layer in the Antarctic Zone because it usually has too low a salinity (see p. 70); it appears to be part of a southward eddy and is eventually returned to the north with the surface water which sinks at the convergence.

## THE ANTARCTIC BOTTOM WATER

According to the historical account given by Merz and Wüst (1922) the first observer to prove the existence of the bottom current was A. von Humboldt in 1814. He found that the deep water below the equatorial region in the Atlantic Ocean was too cold to have been formed at the surface during the winter, and concluded that there was a deep current towards the equator from the polar regions. Since the time of Humboldt the existence of such a current, having its origin in the Antarctic regions, has been demonstrated time and again; it has been found to flow along the sea bottom and it is also known to exist in the Indian and Pacific Oceans. Although the current is so well known, however, its exact mode of formation in the Antarctic region is still a matter of question.

Brennecke (1921, p. 140) pointed out that the observations made during the cruise of the 'Deutschland' and the drift of the 'Endurance' showed that the Antarctic Continent south-west of the Weddell Sea was bordered by a wide continental shelf on which there was a depth of only a few hundred metres. On this shelf the water is cooled right through in winter by convection, and its salinity, already high, is increased as fresh water is removed and salt left behind when sea-ice is formed. Brennecke suggested that the great density of this water would make it sink from the shelf to flow northwards as a bottom current.

Drygalski (1926, pp. 495–7) deduced a similar mode of formation from the Gauss data and regarded the bottom water as deep water which had been cooled by contact with the cold surface water. There was, however, a difficulty in accepting this explanation, because the cold shelf water found by the 'Gauss' in 90° E had a very low salinity; it could not be mixed with the deep water in sufficient quantity to give water of the same temperature as the bottom water without the salinity of the mixture becoming far too low, and in a later paper (1928, p. 278), Drygalski was forced to add that the cooling of the deep water was also effected by climatic influences—presumably through contact with the air. As far as is known at present, however, the deep water never comes into contact with the air, since it is always covered by the poorly saline surface layer, and it is more just to interpret the Gauss data as showing that the bottom water in 90° E is not formed *in situ*; it cannot be formed without some addition of cold and highly saline water from another source.

Schott (1926, p. 428) pointed out that the existing data did not prove that the mode of formation of the bottom water was fundamentally different from that described by Nansen (1912) for the formation of bottom water in the Arctic regions. Nansen supposed that over extensive regions south-east of Greenland, and north and south of Jan Mayen, the water became completely mixed from surface to bottom during the winter, so that the cold surface water could find its way directly into the bottom layer. Wüst (1928) had similar views and suggested that the Antarctic bottom water was formed by the sinking of cold and highly saline surface water in the central part of the Weddell Sea when the cyclonic circulation which prevails there slows down in winter. In a later paper, however (1933, pp. 44–8), he attacks the problem from a new standpoint—that of the potential temperature distribution, and finds that the coldest bottom water is formed as suggested by Brennecke in the south-western part of the sea. While believing this, however, he does not abandon the application of Nansen's principles to the Weddell Sea and supposes that the less cold bottom water—that with a potential temperature between −0·2 and −0·7° C.—is formed by the sinking of cold surface water in winter in a region which extends across the Atlantic Ocean from the region between 60 and 66° S in the Weddell Sea to that between 56 and 60° S in the eastern part of the ocean.

It seems very doubtful, however, that such sinking of surface water ever takes place; the region described has been shown to be a divergence region along the axis of an extended cyclonic circulation (see pp. 92–94) rather than a convergence region as supposed by Wüst, and the bottom water is more likely to well-up towards the surface than the surface water to sink. The upwelling of the bottom water would explain the great vertical extent of the cold water in the region. It is also reasonable to argue from the temperature, salinity and oxygen distribution in the bottom layer that the warmer types of bottom water are formed by the mixing of the bottom current which flows from the south-west corner of the Weddell Sea with more warm deep water.

Although the large area described by Wüst seems most certainly to have no resemblance to those described by Nansen as sources of Arctic bottom water, there is some evidence to show that there is a small region between the South Shetland Islands and the South Orkney Islands for which the analogy is more just. In this region there are only traces of warm water in the deep layer. The observations at St. 637 in 60° 00′ S, 49° 28′ W and St. 638 in 61° 00′ S, 49° 48′ W (Station List, 1932) indicate that the temperature of the deep water does not rise above 0·05° and −0·17 C. At St. 639 in 61° 58′ S, 51° 59′ W the layer is slightly warmer, having a temperature of 0·34° C. Another striking feature of the region, shown by these observations, is the very uniform and low salinity of the deep and bottom waters: below 600 m. the salinity of the water in the whole region covered by the three stations only varies between 34·57 and 34·64 °/₀₀. Both the temperature and salinity distribution suggest that in winter the whole water column from surface to bottom may be homogeneous. This seems to be especially true of the water at St. 637, where although the observations were made in March and the surface water had a temperature of 0·52° C.—at least 2° C. above its probable winter temperature—the salinity of the surface water was as much as 34·35 °/₀₀—only 0·28 °/₀₀ less than the maximum at a depth of 2500 m.

The conclusion that the region is one in which there is active convection between the surface and bottom layers in winter, so that the surface water is carried directly into the bottom layer, is definitely supported by the high oxygen content of the deep and bottom waters; although the observations were made in March, and the deep water, if it sank from the surface during the previous winter, had spent several months shut off from a source of oxygen, its oxygen content at Sts. 637 and 638 had not fallen below 5·19 and 5·38 cc. per litre. At St. 639, where there was warmer water in the deep layer, it had, however, fallen to 4·36 cc. per litre.

The low salinity of the bottom water—less than 34·64 °/₀₀—shows that it was not part of a bottom current from the Weddell Sea, where the salinity of the bottom water is not less than 34·66 °/₀₀. It seems, therefore, safe to conclude that it was formed *in situ* during the winter. The bathymetric chart given by Herdman (1932, pl. xlv) shows that it is not confined to a deep basin shut off from the deep water of the neighbouring seas by shallow submarine ridges; St. 637 lies north of the Scotia Arc and St. 638 and 639 south of it, but the bottom waters appear to be in free communication with those of the Scotia Sea and Weddell Sea. The small difference between the bottom waters on either side of the ridge is in itself an indication that they are formed from the same source—a current sinking from the surface.

It is not unlikely that the region is a convergence between the current which flows northwards out of the Weddell Sea and the drift towards the north-east out of the Drake Passage; a large number of icebergs often of enormous size are generally found there, and although some may be aground in the shallow water found on the Scotia Arc it is also possible that they are accumulated owing to the converging of the currents. The Scotia Arc may play a large part in promoting intense vertical mixing, since the sudden changes in depth are certain to give rise to turbulent movements in the deep currents. The coldest bottom water at Sts. 637–9 had a potential temperature of −0·73° C., but at St. 169 in 60° 49′ S, 51° 00′ W (Station List, 1929), where the bottom water is separated from the water at the same depth to the north and south by shallow submarine ridges (see Herdman, 1932, pl. xlv), the potential temperature was as low as −0·80° C. This temperature is, however, 0·22° C. higher than that of the bottom water in the south-western part of the Weddell Sea, and the temperature distribution as far as it is known at present (Wüst, 1933, pl. ii) leaves no doubt that the region can only be regarded as a secondary source of bottom water.

There are sufficient data available to show that there is no other region in which bottom water is formed farther east along the Scotia Arc. Six series of observations[1] made between 61° 52′ S, 42° 23′ W and 60° 01′ S, 32° 22′ W at the end of winter (November 1932, see Appendix I) showed that there was a relatively large difference of temperature, salinity and oxygen content between the surface water and the deep water. The least difference was found in the shallow water south-east of the South Orkney Islands. The water in the first 100 m. had a temperature of −1·41 to −1·56° C. and a salinity of 34·29–34·37 °/₀₀, whilst the temperature and salinity of the deep water between 400 and 700 m. rise to −0·01° C. and 34·65 °/₀₀. Farther east the differences were greater and showed that there was no likelihood of a uniform water column in winter. Where the depth exceeded 1000 m. the deep water had an oxygen content as low as 4·2–4·3 cc. per litre.

The distribution of potential temperature in the bottom layer has now made it quite clear that the main source of Antarctic bottom water lies in the south-west part of the Weddell Sea and it is generally agreed that in this region the cold and highly saline shelf water sinks down the continental slope, mixes to some extent with the warmer deep water, and then spreads northwards. Mosby (1934, pp. 83–4) has shown from a consideration of the temperature, salinity and oxygen data collected by Brennecke, that the bottom water has the properties of a mixture of shelf water and warm deep water in equal proportions.

The region is usually inaccessible, and since the time of Brennecke no further observations have been made. Although there is no doubt that the cold water sinks from the shelf there is no series of observations to show it actually doing so. Wüst's section to illustrate the sinking (1933, p. 45) is not quite fair, because the bottom water at the shelf station (Deutschland St. 125) is most probably separated from the bottom water farther north by a shallow submarine ridge (see Brennecke, 1921, p. 33). There may, however, be a break in the ridge, and there is also a great expanse of shelf farther west from which the water may sink.

---

[1] At Sts. 1036, 1038, 1039, 1041, 1042 and 1044.

## THE MOVEMENTS OF ANTARCTIC BOTTOM WATER

In order to illustrate the principal movements of the Antarctic bottom water Plate XLIV has been prepared showing the potential temperature of the bottom water at depths greater than 4000 m. In the southern part of the Atlantic Ocean it is based on the charts given by Wüst (1933, pls. i, ii), which are themselves based on all the data that was available including the observations made by the 'Discovery II' and 'William Scoresby'. Other observations made since Wüst's charts were published have also been used. In the Indian and Pacific Oceans the chart is based principally on the observations made during the circumpolar cruise and on a cruise across the southern part of the Antarctic Zone in the Pacific Ocean (Mackintosh, 1935). The 4000-m. bottom contour is based largely on a bathymetric chart published by the American Geographical Society (1931), but the chart has been modified in several localities after a very rough examination of our own soundings; it is therefore only approximately correct.

According to Wüst the coldest bottom water in the open sea lies south of 72° S between 40 and 45° W, where its potential temperature at a depth of 2653 m. (calculated from Brennecke's measurements) is as low as $-1{\cdot}02°$ C. The temperature distribution shows that from this region the cold water spreads first to the north and then to the east. It is very probable that the formation of bottom water, by the sinking of cold surface water, may take place all along the east coast of Graham Land in winter, but the section published by Nordenskjold (1917, pl. 2) and our observations between the South Shetland Islands and the South Orkney Islands show that in the northern part of the region at least, the bottom water is not formed in summer.

Several reasons can be suggested to explain the very large formation of bottom water in the Weddell Sea. The surface water in the southern part of the sea belongs to the current which flows towards the west along the coast of the Antarctic Continent. Even in the Indian Ocean and the eastern part of the Atlantic Ocean this current must have a high salinity in winter, and owing to the continued separation of sea-ice from it as it flows towards the Weddell Sea its salinity must keep increasing. Brennecke (1921) recorded surface salinities as high as $34{\cdot}49\,^{\circ}/_{\circ\circ}$. The deep water in the south and western parts of the Weddell Sea also has a lower temperature and salinity than it has in the open sea in any other part of the Southern Ocean; like the surface water it travels along the continental slope from the western part of the Indian Ocean, and owing to the continued mixing with the surface and bottom waters, it forms a weaker barrier between the surface and bottom layers in the Weddell Sea than it does anywhere else along the edge of the continent.

The effect of the earth's rotation on the current towards the west in the southern part of the sea and towards the north along the east coast of Graham Land also tends to make the water sink in the coastal region. This effect is also likely to be more powerful in the Weddell Sea than in any other Antarctic sector, because of the exceptionally high latitude to which the sea penetrates and because the westward movement is not confined to the surface layer as it principally is in the other sectors, but extended to the deep and bottom layers.

The temperature distribution suggests that the principal movement of the bottom water from the Weddell Sea is towards the east across the Atlantic Ocean; but the low temperature of the bottom water farther north shows that there is also a strong northward movement. In the western half of the ocean Wüst (1933) has traced the current to as far as 40° N.

The distribution of bottom temperature in the Scotia Sea leads Wüst to suppose that some of the bottom water from the Weddell Sea flows through a gap in the southern part of the Scotia Arc, between the South Orkney Islands and the South Sandwich Islands, into the Scotia Sea. On the grounds of the lowest potential temperature recorded, – 0·62° C. at the Deutschland St. 179, he concludes that the depth of the gap in the ridge is 2750 m., so that water from that level in the Weddell Sea can pass through it, and with the help of the Deutschland soundings and the temperature distribution he fixes the longitude of the gap as 34–35° W. In November 1932 the 'Discovery II' made a single line of soundings across the same region, and although they have not yet been examined carefully they show the possibility that there is a gap through the ridge in 33–34° W. They do not prove its existence, however, and subsequent work may show that there is no gap. The evidence of the low bottom temperatures in the Scotia Sea is also not a certain indication that bottom water finds a passage through the ridge from the Weddell Sea. It has already been shown that Antarctic bottom water may be formed in winter between the South Shetland Islands and the South Orkney Islands, on the borders of the Scotia Sea itself. At St. 169 in 60° 49′ S, 51° 00′ W (Station List, 1929) and in the small deep basin just north of the South Orkney Islands potential bottom temperatures as low as –0·80 and –0·68° C. have been measured. These temperatures are lower than those described by Wüst in the neighbourhood of 33–35° W, and they suggest that the cold bottom water may be formed in the southern part of the sea west of the South Orkney Islands.

Wüst also shows that the cold bottom water spreads a short distance towards the west from the Scotia Sea into the Drake Passage where it mixes with the bottom water of the Pacific Ocean. The boundary between the two waters seems to be very well defined and between 60 and 70° W the isotherms run almost north and south. There appears to be no great bottom current either towards the east or west from one ocean to the other.

The principal northward movement of bottom water in the Atlantic Ocean takes place through the deep passage between the Scotia Arc and the mid-Atlantic ridge (Plate XLIV). Wüst (1933) has shown that the Antarctic water from this current can be traced over a distance of 100° of latitude. In the western Atlantic basin it flows directly to 40° N; it also enters the east Atlantic basin through the Romanche Channel—a deep passage through the mid-Atlantic ridge near the equator—and flows northwards as far as 35° N and southwards to the Walfisch ridge in 20–35° S.

Towards the east from the Weddell Sea the bottom water spreads freely across the northern side of the Atlantic-Antarctic basin. Between the Weddell Sea and 30° E the tendency of the cold water to keep to the northern side of the basin is most noticeable, and there is a stream of warmer water along the edge of the Antarctic Continent. This temperature distribution is a plain indication that there is a cyclonic circulation of water in the bottom layer similar to those which have already been described in the surface and deep layers. Like the deep water circulation, it is probably more complete than that of the surface water, since the isotherms in the eastern part of the basin give a more reliable indication of a southward movement to complete the cycle.

The actual temperature and the other properties of the bottom water in the basin are shown in sections 5, 6, and 7 (Plates VII–XII). The lower temperatures, salinities and higher oxygen contents are found on the northern side, and the warmer, more saline, and poorly oxygenated water on the south. The sections were not all made in the same year, and they reveal the fact that relatively large variations may occur in the properties of the bottom water. Although section 6 crosses the northern part of the basin some distance to the east, and therefore farther away from the source of the bottom water than section 5, the temperature of the bottom water was found to be slightly less and the oxygen content considerably greater than those of section 5. It seems most probable that the difference arises because the bottom water in the eastward current had different properties, at the time when section 6 was made, from those which it had fourteen months earlier at the time of section 5. Since the formation of the Antarctic bottom water is probably much greater in winter than in summer, it can only be supposed that the properties of the water in the eastward and northward currents from the Weddell Sea will have a periodical change, the water flowing away from the sea in winter being colder and containing more oxygen than that which leaves the sea in summer. It is hoped that such differences will give a method of measuring the rate of flow of the bottom water, similar to the method already used for the Antarctic intermediate current (Deacon, 1933, pp. 223–6), but the necessary close examination of all the data available has not yet been made.

There is not such a strong current of Antarctic bottom water towards the north in the eastern half of the Atlantic Ocean as there is in the west, the difference between the two streams being most probably the result of the existence of a deeper channel in the west. Wüst in his temperature chart of the Atlantic Ocean and his vertical section along the eastern Atlantic basin (1933, pls. i, vi) has assumed that there is a passage from the Atlantic-Antarctic basin into the Agulhas basin, south of Africa, with a depth of about 4500 m., but our new data indicate that the passage may be shallower. In section 8 (Plates XIII–XV) St. 849 was made in the Agulhas basin, whilst St. 850 was in the Antarctic basin. The section shows that between the two deeps there is a steep ridge which acts as a partial barrier to the northward flow of the bottom water. The ridge between the two basins is probably not so well defined and so shallow throughout its entire length as it is in this section, but even this one section narrows the channel indicated by Wüst. The low potential temperature of the bottom water at the Planet St. 59 (Brennecke, 1909) in 47° 32′ S, 26° 50′ E may be an indication that the station was made in the Antarctic basin, whilst the warmer water at St. 60 in 49° 31′ S, 29° 16′ E might belong to the Agulhas basin. The bottom topography of the region is not well known; the difference between the bottom waters at Sts. 849 and 850 in section 8 suggests that there is a well-defined ridge, but the bottom temperatures at Planet Sts. 58–62 indicate that its shape must be irregular. The existence of an S-shaped ridge such as is shown in Plate XLIV would explain the bottom temperature distribution, and it may also explain the increase of bottom temperature from north to south between Sts. 848 and 849, and the existence of cyclonic eddies in the surface, subsurface and deep currents, such as have already been described (p. 52). The northward movement of the bottom water has been shown by Wüst (1933, p. 74) to be further restricted in passing into the Cape basin, south-west of the Cape of Good Hope (Wüst, pl. viii), and then stopped altogether at the Walfisch ridge. The bottom water found farther north in the eastern Atlantic basin is derived from the western basin through the Romanche Channel, the deep passage through the mid-Atlantic ridge in the neighbourhood of the equator.

An examination of the sections across the Southern Ocean south of the Indian and Pacific Oceans shows that the temperature (Plate XLIV) and salinity of the bottom water increase continuously towards the east, while its oxygen content decreases, and each of these changes indicates that the current from the Weddell Sea spreads eastwards across both of these oceans without being renewed by any further additions of cold, poorly saline, and highly oxygenated water sinking from the continental shelf.

East of Enderby Land the coldest bottom water is found near the continental slope, and the temperature chart suggests that there is no longer a movement towards the west near the continent. The properties of the bottom water on either side of the Kerguelen-Gaussberg ridge in section 9 (Plates XVI–XVIII) are such as show that the water is largely derived from an eastward current from the Weddell Sea. The slightly higher temperature and salinity and lower oxygen content of the water at the southern ends of sections 10 and 11 south of Australia (Plates XIX–XXIV) are also evidence of the existence of an eastward current modified by no other influence than that of mixing with the warm deep water in the layer above. The eastward current appears, however, to have some irregularities; the bending of the isotherms towards the north on the eastern side of the Kerguelen-Gaussberg ridge show that the northward movement is stronger than it is on the west. This bending of the current towards the north is in agreement with Ekman's conclusions (1928) as to the effect of the shallowing of the sea on a deep current, and it must be emphasized that the bottom temperatures found east of the ridge (section 9) are not so low as those found farther south to the west of it. The lower bottom temperature and higher oxygen content at St. 890 in section 11, than at St. 885 in the same latitude in section 10, may also be weak indications of an irregularity in the eastward movement.

At the southern end of section 12 (Plates XXV–XXVII), south of New Zealand, the temperature of the bottom water has increased still further and its oxygen content has decreased. The salinity, however, shows no increase, and since the higher temperature suggests that the bottom current has been mixed with warm deep water the low salinity is difficult to explain. The current may have been diluted with a mixture of shelf water and warm deep water but the low oxygen content of the bottom water argues that there is no such addition and the data as a whole show that the volume of surface water entering the current could only be very small. The salinity difference involved is only about 0·01 °/₀₀ and not more than 0·02 °/₀₀, and although it is unlikely that such an error would enter systematically into the titrations, the difference needs some confirmation before it can be taken seriously.

In section 13 (Plates XXVIII–XXX), the only deep observations were made in the Tasman Sea and in a deep basin near Macquarie Island. The high temperature and low oxygen content of the bottom water in these basins suggests that the bottom current only finds its way into them after being substantially mixed with the warm deep water. It is again remarkable, however, that the relatively large increase of temperature and decrease of oxygen content has been achieved with only a small increase of salinity, and it seems that the bottom water must have been mixed with deep water whose salinity has been reduced almost to that of the bottom current by turbulent mixing; an examination of the sections and a knowledge of the exceptionally rugged nature of the bottom topography in the region suggest that this is not impossible. A rough calculation shows that deep water such as that found between 400 and 800 m. at St. 912 and between 1500 and 2000 m. at St. 919 in section 13 when mixed with the bottom water at St. 905 in section 12 would give rise to water with the same properties as the bottom water at St. 919.

Our observations in the sub-Antarctic and subtropical parts of the Indian ocean serve on the whole to confirm the conclusions reached in a recent discussion of the bottom currents of the Indian Ocean by Wüst (1934). This work suggested that the Indian Ocean was divided by a ridge into eastern and western basins similar to those of the Atlantic Ocean. Wüst draws the ridge northwards from the Kerguelen plateau through New Amsterdam and Rodriguez Islands to the Chagos and Maldive Islands, but more recent soundings by the Murray expedition (not yet published) indicate that a sharper connection exists through the Carlsberg ridge (Schmidt, 1932) to Socotra. The bottom water enters the western basin through the Kerguelen Channel, between the Crozet Islands and Kerguelen, and it enters the eastern basin through a gap in the Indian-Pacific cross-ridge that is traversed by section 10[1]; the depth of the passage seems to be just over 4000 m.

The observations at the southern end of section 14 (Plates XXXI–XXXIII) show that the bottom water just north of the Ross Sea also has properties which indicate that it belongs to the eastward current from the Weddell Sea, and they give a clear indication that there is no stream of cold poorly saline bottom water sinking from the

---

[1] See List of Oceanic Depths received at the Admiralty during 1932 (Hydrographic Department, 1933), and Deacon (1934, p. 131).

Ross Sea. The lowest bottom temperature measured in section 14 was 0·09° C. at a depth of 3500 m., and the properties of this water are such as may result from the mixing of the coldest bottom water found in section 11, − 0·19° C. at 3500 m., with warm deep water. It is however impossible to arrive at any final conclusions with regard to this region until observations have been made in the channel which is indicated at the southern ends of sections 12 and 13, and in the region between the Balleny Islands and Cape Adare; owing to our observations being made in winter these localities were quite inaccessible.

Although the temperature and salinity distribution in section 14 shows that no cold poorly saline bottom water sinks from the Ross Sea, the water between 65 and 70° S has a slightly higher oxygen content than that in the neighbourhood of the Antarctic Continent south of Australia. The difference is, however, not more than 0·07 cc. per litre, and since the observations in the two localities were not made in the same year (the southern part of section 14 in 1934, and the observations south of Australia in 1932) it is not large enough to be regarded as contradictory to the evidence from temperature and salinity. Larger differences were noted between sections 5 and 6 in the Atlantic Ocean (see p. 112), and there is good reason to believe that the oxygen content of the water in the eastward current from the Weddell Sea varies considerably from season to season and perhaps from year to year.

The soundings made so far in the Ross Sea (Bathymetric Chart, American Geographical Society, 1931) show that the greater part of the sea, which has a depth of 500–1000 m., is shut off from the open ocean to the north by a relatively shallow ridge running across the mouth of the sea from Cape Adare to King Edward VII Land. The soundings on the ridge are less than 500 m., but the chart shows that there is probably a slightly deeper channel through the ridge near the coast of Queen Victoria Land. Our observations suggest that there is no deep channel, because although the data from the southern part of the sea (Sts. RS 13–29) show that the bottom water has a temperature between −0·30 and −1·97° C., the data available so far from the region outside the sea indicate that none of this water escapes into the open ocean. Although the conditions in winter in the Ross Sea may closely resemble those found by Brennecke (1921) in the neighbourhood of Vahsel Bay in the southern part of the Weddell Sea, and a large volume of water may be formed with similar properties to that which sinks from the continental shelf south-west of the Weddell Sea, the water apparently cannot reach the ocean outside, and as far as can be seen at present the Ross Sea produces no cold bottom current.

In section 15 (Plates XXXIV–XXXVI), between 160 and 130° W, the bottom water is still warmer and more saline than it is north of the Ross Sea, but it advances farther towards the north. The relatively high temperature and salinity show that the advance is not caused by the current being reinforced by more water sinking from the continental shelf, and there is no doubt that it is due to the influence of the Cape Adare-Easter Island ridge. Section 14 only crosses the ridge in 62–65° S, but section 15 follows the ridge as far as 55° S, and a comparison of the two shows that the eastward bottom current bends towards the north in the shallow water. The observations used in the construction of Plate XLIV show that on the other side of the ridge, between 150 and

140° W, the bottom current bends back to the south. The deflection of the current is in each instance in agreement with the effect of a shallowing and deepening of the ocean on the easterly current as deduced theoretically by Ekman (1928). The same observations also show that a small part of the bottom current turns back towards the west in the neighbourhood of the continental slope, giving rise to a small cyclonic movement. The bottom water adjacent to the ridge which closes the Ross Sea thus appears to flow towards the west, and in section 14 the coldest bottom water is not found farthest south but between 65 and 70° S. The cyclonic movement is, however, only small and weak compared with that in the Atlantic-Antarctic basin.

Farther east in the Pacific Ocean the temperature and salinity of the bottom current go on increasing while the oxygen content decreases, and the bottom water in sections 16 and 17 (Plates XXXVII–XL, XLII) still has the properties of the eastward current from the Weddell Sea mixed with more warm deep water. A comparison of the temperature and salinity of the bottom water in section 18, in 80° W (Plates XLI, XLII), with those of the bottom water in section 16, leads to the same conclusion. A comparison of the oxygen data shows, however, that the water in 80° W is slightly richer in oxygen. The difference is very small (only 0–0·1 cc. per litre), and it may be due to a seasonal change in the properties of the current; but the close proximity of the section to the Atlantic Ocean and the fact that the difference is shown by both the 1932 and 1934 observations (Sts. 988–94, 972–4, and Sts. 1312, 1247–1245) suggests that it may be due to a very small inflow of bottom water from the Scotia Sea.

A comparison of the temperature distribution in sections 1 and 18 (Plates II, XLI) across the eastern and western ends of the Drake Passage shows that the bottom water is slightly colder at the Atlantic end; the temperature gradient, particularly below a depth of 3000 m., is sharper, and on the southern side of the passage the bottom water is 0·3–0·4° C. colder than it is at the Pacific end. The water at the Atlantic end is also slightly less saline and richer in oxygen (Plates II, XLI–XLII), and these properties, together with the low temperature, show that it does not belong entirely to the current which flows eastward round almost the whole of the continent, but partly to a westward movement from the Scotia Sea. A closer investigation of the data will be needed before the limit of the westward current can be determined exactly; but it is clear from the temperature chart constructed by Wüst (1933, pl. ii) that the current diminishes rapidly in 55–70° W, and probably not more than a trace, very close to the continental slope, flows farther west. The slightly higher oxygen content of the bottom water in section 18 indicates that such a trace of Atlantic water reaches 80° W.

A more careful examination of the data must also be made before it is possible to say what happens to the final traces of water from the circumpolar bottom current; part of the current may continue towards the east through the Drake Passage above the colder water which flows westwards from the Scotia Sea, but it is also possible that the whole of the current bends towards the north in the eastern part of the Pacific Ocean together with the highly saline deep current (p. 104).

An examination of the properties of the bottom water such as that made in the preceding pages shows that it is no longer possible to assume that the bottom water is formed by the sinking of shelf water all round the Antarctic continent, nor as Sverdrup (1931, p. 102) supposes, that it is deflected to the left on account of the earth's rotation as it flows northwards, turning towards the west. It is on the contrary formed only in one region, the Weddell Sea, and its principal movement is towards the east. The northward currents at the bottom of the Atlantic, Indian and Pacific Oceans are, however, not derived only from the eastward current. Some of the warm water which flows southwards in the deep layer becomes mixed with the bottom water and returns to the north. The temperature and salinity distribution in the deep and bottom layers of the Indian Ocean shows that some of the North Atlantic deep water, which enters the ocean south of the Cape of Good Hope, spreads northwards in the bottom layer, and it was also shown in the section on Pacific Ocean deep currents that the northward movement in the bottom layer is largely composed of the highly saline water which enters the Pacific from the Indian and Atlantic Oceans, south of Australia.

The part played by cold shelf water in the formation of the northward currents by cooling the warm deep water in the neighbourhood of the Antarctic Continent is not fully understood. It is certain that the coldest bottom water in all three oceans comes from the Weddell Sea, and that the increase of temperature and salinity towards the east is due to the mixing of this current with warm and highly saline water flowing southwards in the deep layer. The cold surface water apparently does not mix with the deep water near the continental shelf and sink into the bottom layer. Drygalski's work in the neighbourhood of Gaussberg (1926) showed that the surface water on the Antarctic shelf never reached so high a salinity that by mixing with the deep water it could produce water of the same temperature and salinity as that found in the bottom layer. As far as is known at present, water with a sufficient salinity is only formed in the Weddell Sea, where the formation of bottom water plainly takes place, and in the Ross Sea, where bottom water is formed without being able to escape to the open ocean. At other points round the Antarctic shelf the cold surface water may, however, exert a less direct influence on the bottom water movements by mixing with the warm deep water: a small volume of shelf water mixed with deep water may combine with the eastward bottom current without having any appreciable effect on the gradual change of its properties, and further work may show that the cooling and dilution of the deep current by the shelf water is just as essential to the continued existence of the eastward and northward currents as the bottom current from the Weddell Sea.

# APPENDIX I

*The temperature, salinity, and oxygen distribution at stations not shown in the vertical sections, and preliminary figures for stations made subsequent to the circumpolar cruise*

*Stations east of New Zealand*

| Depth | Temperature °C. | Salinity ‰ | Oxygen cc. per litre | Temperature °C. | Salinity ‰ | Oxygen cc. per litre | Temperature °C. | Salinity ‰ | Oxygen cc. per litre |
|---|---|---|---|---|---|---|---|---|---|
| | St. 1277, 53° 58′ S, 172° 10′ W, 23. i. 34, 5285 m. | | | St. 1278, 51° 43′ S, 173° 18′ W 24. i. 34, 5389 m. | | | St. 1279, 49° 27′ S, 174° 44′ W, 25. i. 34, 5313 m. | | |
| 0 | 8·45 | 34·20 | 6·07 | 9·18 | 34·25 | 5·97 | 10·56 | 34·14 | 5·83 |
| 10 | 8·45 | 34·20 | — | 9·18 | 34·25 | — | 10·56 | 34·14 | — |
| 20 | 8·45 | 34·20 | 6·08 | 9·18 | 34·25 | 5·96 | 10·56 | 34·14 | 5·83 |
| 30 | 8·45 | 34·20 | — | 9·18 | 34·26 | — | 10·56 | 34·14 | — |
| 40 | 8·45 | 34·20 | 6·08 | 9·18 | 34·26 | 5·98 | 10·56 | 34·14 | 5·83 |
| 50 | 8·45 | 34·20 | — | 9·18 | 34·26 | — | 10·53 | 34·14 | — |
| 60 | 8·45 | 34·20 | 6·05 | 9·17 | 34·26 | 5·95 | 9·76 | 34·14 | 5·92 |
| 80 | 8·13 | 34·19 | — | 8·05 | 34·31 | — | 6·87 | 34·15 | — |
| 100 | 6·78 | 34·15 | 6·16 | 7·95 | 34·33 | 5·91 | 6·63 | 34·16 | 6·13 |
| 150 | 6·59 | 34·27 | 5·90 | 6·85 | 34·29 | 5·97 | 6·85 | 34·31 | 5·84 |
| 200 | 6·55 | 34·28 | 5·79 | 7·06 | 34·35 | 5·76 | 6·16 | 34·22 | 5·92 |
| 300 | 5·98 | 34·27 | 5·78 | 6·82 | 34·36 | 5·61 | 5·53 | 34·19 | 5·89 |
| 400 | 5·79 | 34·29 | 5·51 | 6·57 | 34·34 | 5·63 | 5·40 | 34·23 | 5·52 |
| 600 | 4·70 | 34·31 | 4·86 | 5·26 | 34·22 | 5·51 | 4·56 | 34·31 | 4·68 |
| 800 | 3·73 | 34·32 | 4·42 | 4·43 | 34·26 | 4·76 | 3·49 | 34·33 | 4·43 |
| 1000 | 3·14 | 34·40 | 4·04 | 3·69 | 34·33 | 4·31 | 3·22 | 34·41 | 3·91 |
| 1500 | 2·44 | 34·60 | 3·69 | 2·68 | 34·52 | 3·74 | 2·46 | 34·59 | 3·67 |
| 2000 | 2·23 | 34·72 | 3·74 | 2·34 | 34·66 | 3·64 | 2·21 | 34·70 | 3·70 |
| 2500 | 1·94 | 34·76 | 3·95 | 2·08 | 34·68 | 3·81 | 1·94 | 34·76 | 3·97 |
| 3000 | 1·53 | 34·76 | 4·14 | 1·74 | 34·75 | 4·00 | 1·56 | 34·75 | 4·18 |
| 3500 | 1·21 | 34·75 | 4·26 | 1·38 | 34·75 | 4·14 | 1·22 | 34·75 | 4·25 |

| Depth | Temperature °C. | Salinity ‰ | Oxygen cc. per litre | Depth | Temperature °C. | Salinity ‰ | Oxygen cc. per litre |
|---|---|---|---|---|---|---|---|
| | St. 1280, 47° 17′ S, 175° 51′ W, 26. i. 34, 5130 m. | | | | St 1281, 40° 43·2′ S, 179′ 48·6′ W 28. i. 34, 2579 m. | | |
| 0 | 12·72 | 34·78 | 5·59 | 0 | 15·73 | 34·84 | 5·34 |
| 10 | 12·72 | 34·78 | — | 10 | 15·78 | 34·84 | — |
| 20 | 12·72 | 34·78 | 5·57 | 20 | 15·73 | 34·84 | 5·34 |
| 30 | 12·72 | 34·78 | — | 30 | 15·23 | 34·84 | — |
| 40 | 12·72 | 34·78 | 5·57 | 40 | 14·73 | 34·84 | 5·50 |
| 50 | 12·71 | 34·78 | — | 50 | 13·98 | 34·84 | — |
| 60 | 12·69 | 34·78 | 5·54 | 60 | 13·78 | 34·84 | 5·29 |
| 80 | 10·67 | 34·83 | — | 80 | 13·48 | 34·84 | — |
| 100 | 10·49 | 34·84 | 5·43 | 100 | 12·38 | 34·89 | 5·17 |
| 150 | 9·96 | 34·77 | 5·47 | 150 | 11·25 | 34·91 | 5·31 |
| 200 | 9·58 | 34·76 | 5·44 | 200 | 11·36 | 34·93 | 5·31 |
| 300 | 9·18 | 34·75 | 4·75 | 300 | 10·92 | 34·89 | 5·03 |
| 400 | 8·41 | 34·66 | 5·15 | 400 | 9·69 | 34·78 | 4·50 |
| 600 | 7·69 | 34·56 | 4·85 | 600 | 7·54 | 34·59 | 4·32 |
| 800 | 6·78 | 34·45 | 4·60 | 800 | 4·90 | 34·50 | 3·90 |
| 1000 | 5·80 | 34·45 | 4·15 | 1000 | 4·03 | 34·51 | 3·56 |
| 1500 | 3·19 | 34·47 | 3·90 | 1500 | 2·78 | 34·60 | 3·39 |
| 2000 | 2·44 | 34·66 | 3·53 | 2000 | 2·14 | 34·67 | 3·22 |
| 2500 | 2·21 | 34·75 | 3·71 | 2500 | 1·67 | 34·75 | 3·78 |
| 3000 | 1·82 | 34·78 | 3·90 | | | | |
| 3500 | 1·45 | 34·77 | 4·15 | | | | |

*Stations in the neighbourhood of the Scotia Arc, between the South Orkney Islands and the South Sandwich Islands*

| Depth | Temperature °C. | Salinity °/₀₀ | Oxygen cc. per litre | Temperature °C. | Salinity °/₀₀ | Oxygen cc. per litre | Temperature °C. | Salinity °/₀₀ | Oxygen cc. per litre |
|---|---|---|---|---|---|---|---|---|---|
| | St. 1036, 61° 52·3′ S, 42° 23·1′ W<br>25. xi. 32, 779 m. | | | St. 1038, 61° 39·4′ S, 40° 00·3′ W<br>25. xi. 32, 3410 m. | | | St. 1039, 61° 29·9′ S, 37° 14·5′ W<br>26. xi. 32, 3692 m. | | |
| 0 | −1·41 | 34·29 | 7·45 | −1·31 | 34·29 | 7·26 | −0·99 | 34·23 | 7·38 |
| 10 | −1·44 | 34·30 | — | −1·21 | 34·33 | — | −1·00 | 34·23 | — |
| 20 | −1·48 | 34·30 | 7·36 | −1·21 | 34·38 | 7·29 | −1·01 | 34·23 | 7·37 |
| 30 | −1·49 | 34·30 | — | −1·23 | 34·38 | — | −1·01 | 34·23 | — |
| 40 | −1·50 | 34·30 | 7·32 | −1·22 | 34·38 | 7·18 | −1·04 | 34·23 | 7·32 |
| 50 | −1·50 | 34·30 | — | −1·21 | 34·38 | — | −1·30 | 34·29 | — |
| 60 | −1·58 | 34·30 | 6·96 | −1·21 | 34·38 | 7·15 | −1·31 | 34·33 | 6·83 |
| 80 | −1·53 | 34·35 | — | −1·21 | 34·39 | — | −1·41 | 34·37 | — |
| 100 | −1·56 | 34·37 | 6·56 | −1·41 | 34·39 | 6·63 | −1·30 | 34·38 | 6·50 |
| 150 | −1·24 | 34·44 | 5·97 | −0·82 | 34·53 | 5·42 | −0·52 | 34·48 | 5·56 |
| 200 | −0·80 | 34·54 | 5·35 | −0·24 | 34·64 | 4·80 | −0·90 | 34·49 | 5·36 |
| 300 | −0·34 | 34·62 | 5·00 | 0·09 | 34·65 | 4·55 | −0·11 | 34·63 | 4·69 |
| 400 | −0·01 | 34·65 | 4·85 | 0·25 | 34·66 | 4·46 | 0·26 | 34·65 | 4·43 |
| 600 | −0·18 | 34·65 | 4·72 | 0·40 | 34·68 | 4·28 | 0·44 | 34·69 | 4·26 |
| 700 | −0·19 | 34·65 | 4·69 | — | — | — | — | — | — |
| 800 | — | — | — | 0·33 | 34·68 | 4·34 | 0·42 | 34·69 | 4·23 |
| 1000 | — | — | — | 0·23 | 34·67 | 4·31 | 0·31 | 34·68 | 4·22 |
| 1500 | — | — | — | 0·01 | 34·67 | 4·56 | 0·12 | 34·67 | 4·44 |
| 2000 | — | — | — | −0·19 | 34·66 | 4·61 | −0·09 | 34·66 | 4·50 |
| 2500 | — | — | — | −0·39 | 34·66 | 4·81 | −0·28 | 34·66 | 4·75 |
| 3000 | — | — | — | −0·54 | 34·66 | 5·00 | −0·49 | 34·66 | 4·95 |
| | St. 1041, 60° 31·3′ S, 36° 19·5′ W<br>26. xi. 32, 1737 m. | | | St. 1042, 60° 07·9′ S, 34° 19·0′ W<br>27. xi. 32, 2055 m. | | | St. 1044, 60° 00·6′ S, 32° 21·6′ W<br>27. xi. 32, 763 m. | | |
| 0 | −1·05 | 34·11 | 7·04 | −1·28 | 34·20 | 6·88 | −1·21 | 34·05 | 7·53 |
| 10 | −1·16 | 34·11 | — | −1·41 | 34·21 | — | −1·21 | 34·05 | — |
| 20 | −1·22 | 34·12 | 6·96 | −1·42 | 34·21 | 6·81 | −1·21 | 34·05 | 7·53 |
| 30 | −1·28 | 34·13 | — | −1·44 | 34·21 | — | −1·22 | 34·05 | — |
| 40 | −1·31 | 34·14 | 6·96 | −1·49 | 34·21 | 6·82 | −1·34 | 34·05 | 7·52 |
| 50 | −1·33 | 34·16 | — | −1·51 | 34·22 | — | −1·48 | 34·09 | — |
| 60 | −1·40 | 34·19 | 6·82 | −1·52 | 34·27 | 6·58 | −1·59 | 34·17 | 6·74 |
| 80 | −1·41 | 34·30 | — | −1·46 | 34·34 | — | −1·57 | 34·22 | — |
| 100 | −0·91 | 34·40 | 5·78 | −1·22 | 34·39 | 5·99 | −1·46 | 34·28 | 6·28 |
| 150 | −0·19 | 34·54 | 5·08 | −0·41 | 34·54 | 5·20 | −0·82 | 34·45 | 5·50 |
| 200 | 0·15 | 34·61 | 4·83 | 0·06 | 34·64 | 4·86 | −0·31 | 34·56 | 5·05 |
| 300 | 0·22 | 34·66 | 4·69 | 0·17 | 34·66 | 4·67 | 0·08 | 34·64 | 4·70 |
| 400 | 0·50 | 34·66 | 4·62 | 0·29 | 34·66 | 4·55 | 0·31 | 34·66 | 4·62 |
| 600 | 0·27 | 34·66 | 4·50 | 0·27 | 34·66 | 4·43 | 0·18 | 34·66 | 4·55 |
| 700 | — | — | — | — | — | — | 0·19 | 34·66 | 4·63 |
| 800 | 0·27 | 34·67 | 4·48 | 0·28 | 34·67 | 4·39 | — | — | — |
| 1000 | 0·27 | 34·67 | 4·33 | 0·26 | 34·67 | 4·32 | — | — | — |
| 1500 | 0·22 | 34·67 | 4·36 | 0·10 | 34·67 | 4·47 | — | — | — |

## REFERENCES

ARCTOWSKI, H. and MILL, H. R., 1908. *Relations thermiques: Rapport sur les observations thermométriques faites aux stations de sondages.* Expédition Antarctique Belge: Résultats du Voyage du S.Y. 'Belgica' en 1897–1899. Rapports scientifiques, V, Part II, Antwerp.

BONGRAIN, M., 1914. *Description des Côtes et Banquises, Instructions Nautiques.* Deuxième Expédition Antarctique Française (1908–1910), Paris.

BRENNECKE, W., 1909. Forschungsreise S.M.S. 'Planet', 1906/1907, III, Ozeanographie. Reichs-Marine-Amt, Berlin.

—— 1921. *Die ozeanographischen Arbeiten der Deutschen Antarktischen Expedition,* 1911–1912. Arch. deutsch. Seewarte, XXXIX, Hamburg.

BUCHAN, A., 1895. *Report on Oceanic Circulation, based on the Observations made on board H.M.S. 'Challenger', and other observations.* Report on the Scientific Results of the Voyage, Summary of Results, Part II, Appendix, London.

CLOWES, A. J., 1933. *Influence of the Pacific on the Circulation in the South-West Atlantic Ocean.* Nature, CXXXI, p. 189, London.

—— 1934. *Hydrology of the Bransfield Strait.* Discovery Reports, IX, pp. 1–64, Cambridge.

CLOWES, A. J., and DEACON, G. E. R., 1935. *The Deep-Water Circulation of the Indian Ocean.* Nature, CXXXVI, pp. 936–8, London

DAEHLI, A., 1931. *Sydishavet, Kart over Isgrenser.* Hvalfangernes Assuranceforening, Sandefjord.

DAVIS, J. K., 1919. With the 'Aurora' in the Antarctic, London.

DEACON, G. E. R., 1933. *A General Account of the Hydrology of the South Atlantic Ocean.* Discovery Reports, VII, pp. 171–238, pls. viii–x, Cambridge.

—— 1934. *Die Nordgrenzen antarktischen und subantarktischen Wassers im Weltmeer.* Ann. Hydrog. Mar. Meteorol., IV, pp. 129–36, pl. 14, Hamburg.

—— 1934. *Nochmals: wie entsteht die antarktische Konvergenz?* Ann. Hydrog. Mar. Meteorol., XII, pp. 475–8, pl. 61, Hamburg.

DEFANT, A., 1928. *Die systematische Erforschung des Weltmeeres.* Zeit. Ges. Erdkunde, Berlin, pp. 459–505.

DRYGALSKI, E. VON, 1926. *Ozean und Antarktis.* Meereskundliche Forschungen und Ergebnisse der Deutschen Südpolar-Expedition 1901–1903, Berlin and Leipzig.

—— 1928. *The Oceanographical Problems of the Antarctic.* Problems of Polar Research, New York, pp. 269–83 (translated from the German original).

EKMAN, V. W., 1928. *A Survey of some Theoretical Investigations in Ocean Currents.* Journ. Conseil, III, pp. 295–327, Copenhagen.

—— 1932. *Studien zur Dynamik der Meeresströmungen.* Gerlands Beit. Geophysik, pp. 385–438, Leipzig.

FRICKER, K. V., 1898. Antarktis, Berlin.

HART, T. J., 1934. *On the Phytoplankton of the South-West Atlantic and the Bellingshausen Sea,* 1929–31. Discovery Reports, VIII, pp. 1–268, Cambridge.

HERDMAN, H. F. P., 1932. *Report on Soundings taken during the Discovery Investigations,* 1926–32. Discovery Reports, VI, pp. 205–36, pls. xlv–xlvii, charts 1–7, Cambridge.

The Hydrographic Department, Admiralty, London, 1927. Australia Pilot, I. South coast of Australia from Cape Leeuwin to Cape Northumberland.

—— 1928. South America Pilot, Part II. Magellan Strait, Tierra del Fuego, and west coast of South America from Cape Virgins to Cape Raper.

—— 1929. Australia Pilot, II. South and east coasts of Australia from Cape Northumberland to Port Jackson, including Bass Strait and Tasmania.

—— 1929. Africa Pilot, Part III. South and east coasts of Africa from Table Bay to Ras Hafún.

—— 1930. The Antarctic Pilot. The coasts of Antarctica and all islands southward of the usual route of vessels.

—— 1930. The New Zealand Pilot. The coasts of the north and south islands of New Zealand, Stewart Island and adjacent islands, Kermadec, Chatham, Bounty, Antipodes, Auckland and Campbel Islands.

The Hydrographic Department, Admiralty, London, 1932. South America Pilot, Part I. North-eastern and eastern coasts of South America from Cape Orange to Cape Virgins, including the Falkland Islands.

—— 1934. Australia Pilot, v. The northern, north-western, and western coasts of Australia from the southern point at the western entrance to Endeavour Strait to Cape Leeuwin.

ISACHSEN, G., 1934. Norvegia rundt Sypollandet. Norvegia Ekspedisjonen, 1930–1931, Oslo.

KEMP, S. and NELSON, A. L., 1931. *The South Sandwich Islands*. Discovery Reports, III, pp. 133–98, Cambridge.

KLAEHN, J., 1911. *Über die Meeresströmungen zwischen Kap Horn und der La Plata-Mündung*. Ann. Hydrog. Mar. Meteorol., XII, pp. 647–65, pls. 34–38, Hamburg.

KRÜMMEL, O., 1911. Handbuch der Ozeanographie, I, II, Stuttgart.

MACKINTOSH, N. A., 1935. *Recent Antarctic Research undertaken by the Discovery Committee. The R.R.S. 'Discovery II'*, 1933–35. Nature, CXXXVI, pp. 629–30, London.

MARR, J. W. S., 1935. *The South Orkney Islands*. Discovery Reports, x, pp. 283–382, pls. xii–xxv, chart I, Cambridge.

MEINARDUS, W., 1923. *Meteorologische Ergebnisse der Deutschen Südpolar-Expedition* 1901–1903. Deutsche Südpolar-Expedition, III, Meteorologie, Bd. I, Heft I, Berlin.

MERZ, A. and WÜST, G., 1922. *Die atlantische Vertikalzirkulation*. Zeit. Ges. Erdkunde, Berlin, Nr. 1/2, pp. 1–35.

MERZ, A., 1925. *Die Deutsche Atlantische Expedition auf dem Vermessungs- und Forschungsschiff 'Meteor'*. Sitzungsbericht Berlin. Akad. Wiss.

MEYER, H. H. F., 1923. *Die Oberflächenströmungen des Atlantischen Ozeans im Februar*. Veröffentl. Inst. Meereskunde, Berlin, Reihe A, Heft XI, pp. 1–35.

MICHAELIS, G., 1923. *Die Wasserbewegung an der Oberfläche des Indischen Ozeans im Januar und Juli*. Veröffentl. Inst. Meereskunde, Berlin, Reihe A, Heft VIII, pp. 1–32, Karten 1–4.

MÖLLER, L., 1926. *Methodisches zu den Vertikalschnitten längs* 35·4° *S und* 30° *W im Atlantischen*. Veröffentl. Inst. Meereskunde, Berlin, pp. 1–47.

—— 1929. *Die Zirkulation des Indischen Ozeans*. Veröffentl. Inst. Meereskunde, pp. 1–48, Berlin.

—— 1933. *Zur Frage der Tiefenzirkulation im Indischen Ozean*. Ann. Hydrog. Mar. Meteorol., pp. 233–6, Hamburg.

MOSBY, H., 1934. *The Waters of the Atlantic Antarctic Ocean*. Scientific Results of the Norwegian Antarctic Expeditions, 1927–1928 *et seqq*., No. 11, Oslo.

MOSSMAN, R. C., 1918. *The Climate and Meteorology of Antarctic and Sub-Antarctic Regions*. Journ. Scot. Meteorol. Soc., XVIII, No. XXXV, pp. 18–29.

MÜHRY, A., 1864. *Die Meeresströmungen an der Südspitze Afrikas*. Petermanns Mittheilungen, x, pp. 34–5.

MURRAY, J., 1895. A summary of the Scientific Results obtained at the sounding, dredging, and trawling stations of H.M.S. 'Challenger', London.

NANSEN, F., 1912. *Das Bodenwasser und die Abkühlung des Meeres*. Int. Rev. gesamt. Hydrobiol. und Hydrog., v, pp. 1–42, Leipzig.

NORDENSKJÖLD, O., 1917. *Die ozeanographischen Ergebnisse*. Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, I, No. 2, Stockholm. (Separates of this paper are dated 1917.)

PETERMANN, A., 1865. *Der Nordpol und Südpol, mit Bemerkungen über die Strömungen der Polar-Meere*. Petermanns Mitteilungen, XI, pp. 146–60, pl. 5.

REICHARD, A. C., 1911. *Temperatur- und Salzgehaltbestimmungen im südwestlichen Stillen Ozean*, 1910. Ann. Hydrog. Mar. Meteorol., p. 521, Hamburg.

RENNELL, J., 1832. An investigation of the currents of the Atlantic Ocean, and of those which prevail between the Indian Ocean and the Atlantic, London.

ROUCH, J., 1911. *Observations météorologiques*. Deuxième Expédition Antarctique Française (1908–1910), Paris.

—— 1913. *Océanographie Physique*. Deuxième Expédition Antarctique Française (1908–1910), Paris.

RUUD, J. T., 1930. *Nitrates and Phosphates in the Southern Seas*. Journ. Conseil, v, No. 3, pp. 347–60, Copenhagen.

SCHMIDT, J., 1932. Dana's Togt omkring Jorden, 1928–1930. Copenhagen.

SCHOTT, G., 1902. *Ozeanographie und maritime Meteorologie*. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition auf dem Dampfer 'Valdivia' 1898–1899, I, Jena.

SCHOTT, G. and SCHU, F., 1910. *Die Wärmeverteilung in den Tiefen des Stillen Ozeans.* Ann. Hydrog. Mar. Meteorol., pp. 2–25, pl. 1–15, Hamburg.

SCHOTT, G., 1926. *Geographie des Atlantischen Ozeans*, Hamburg.

—— 1926. *Die Tiefwasserbewegungen des Indischen Ozeans.* Ann. Hydrog. Mar. Meteorol., pp. 417–31, pl. 29, Hamburg.

—— 1928. *Die Verteilung des Salzgehaltes im Oberflächenwasser der Ozeane.* Ann. Hydrog. Mar. Meteorol., V, pp. 145–66, pl. xiv, Hamburg.

—— 1933. *Auftriebwasser an den australischen Westküsten? Ja und Nein!* Ann. Hydrog. Mar. Meteorol., LXI, pp. 225–33, pl. 28, Hamburg.

—— 1933. *Die britische Tiefsee-Expedition auf 'Discovery II'* 1932/3. Ann. Hydrog. Mar. Meteorol., pp. 342–4, Hamburg.

—— 1934. *Die Verteilung des Salzgehaltes im Oberflächenwasser der Ozeane.* The James Johnstone Memorial Volume, pp. 235–41, Liverpool.

—— 1935. Geographie des Indischen und Stillen Ozeans, Hamburg.

STATION LIST, 1929. *Discovery Investigations Station List* 1925–1927. Discovery Reports, I, pp. 1–140, pls. i–vi, Cambridge.

—— 1930. *Discovery Investigations Station List* 1927–1929. Discovery Reports, III, pp. 1–132, pls. i–x, Cambridge.

—— 1932. *Discovery Investigations Station List* 1929–1931. Discovery Reports, IV, pp. 1–232, pls. i–v, Cambridge.

SVERDRUP, H. U., 1931. *The Origin of the Deep Water of the Pacific Ocean as indicated by the Oceanographic work of the 'Carnegie'.* Gerlands Beit. Geophysik, XXIX, pp. 95–105, Leipzig.

—— 1933. *On Vertical Circulation in the Ocean due to the action of the Wind with application to conditions within the Antarctic Circumpolar Current.* Discovery Reports, VII, pp. 139–70, Cambridge.

—— 1934. *Wie entsteht die Antarktische Konvergenz?* Ann. Hydrog. Mar. Meteorol., VIII, pp. 315–17, Hamburg.

THOMSEN, H., 1933. *The Circulation in the Depths of the Indian Ocean.* Journ. Conseil, VIII, p. 73–79, Copenhagen.

THORADE, H., 1933. *Verfeinerung der Ekmanschen Theorie.* Ann. Hydrog. Mar. Meteorol., pp. 387–9, Hamburg.

TIZARD, T. H., MOSELY, H. N., BUCHANAN, J. Y., and MURRAY, J., 1885. Narrative of the cruise of H.M.S. 'Challenger', 1873–76. London.

WILCKENS, O., 1933. *Der Südantillen-Bogen.* Geologischer Rundschau, XXIV, 5, pp. 320–35.

WILLIMZIK, W., 1924. *Die antarktischen Oberflächenströmungen zwischen 50° O und 110° O.* Veröffentl. Inst. Meereskunde, Reihe A, Heft 13 II, pp. 25–9, Berlin.

—— 1929. *Die Strömungen im subtropischen Konvergenzgebiet des Indischen Ozeans.* Veröffentl. Inst. Meereskunde, pp. 1–27, pls. 1–4, Berlin.

WORDIE, J. M., 1921. *The Ross Sea Drift of the 'Aurora' in* 1915–1916. Geogr. Journ., LVIII, pp. 219–24, London.

WÜST, G., 1926. *Bericht über die ozeanographischen Untersuchungen. Die Deutsche Atlantische Expedition auf dem Vermessungs- und Forschungsschiff 'Meteor'.* Zeit. Ges. Erdkunde, Berlin, Nr. 5/6, pp. 231–50.

—— 1928. *Der Ursprung der Atlantischen Tiefenwässer.* Zeit. Ges. Erdkunde, Berlin, pp. 506–34.

WÜST, G., BÖHNECKE, G. and MEYER, H. F., 1932. *Ozeanographische Methoden und Instrumente.* Wissenschaftliche Ergebnisse der Deutschen Atlantischen Expedition auf dem Forschungs- und Vermessungsschiff 'Meteor' 1925–27, IV, Teil 1, Berlin und Leipzig.

WÜST, G., 1929. *Schichtung und Tiefenzirkulation des Pazifischen Ozeans.* Veröffentl. Inst. Meereskunde, pp. 1–64, pls. 1–4, Berlin.

—— 1933. *Das Bodenwasser und die Gliederung der Atlantischen Tiefsee.* Wissenschaftliche Ergebnisse der Deutschen Atlantischen Expedition auf dem Forschungs- und Vermessungsschiff 'Meteor' 1925–27, VI, Teil 1.

—— 1934. *Anzeichen von Beziehungen zwischen Bodenstrom und Relief in der Tiefsee des Indischen Ozeans.* Naturwissenschaften, XXII, Heft XVI, pp. 241–4, Berlin.

# NOTE ON THE PLATES

Plates II–XLIII show the distribution of temperature, salinity and oxygen content, in vertical sections along the lines marked sections 1 to 19 on the circumpolar chart in Plate I. The temperatures are always expressed as ° C, the salinities as $^{\circ}/_{\circ\circ}$ according to Knudsen's Tables (1901), and the oxygen contents as c.c. per litre.

Each of the sections, except 2 and 19, has been drawn projected on to a meridian so that the horizontal distances do not represent actual distances along the sections but only differences of latitude. The latitude and depth scales have been maintained the same throughout so that the sections are comparable; the exaggeration of the vertical scale with respect to the horizontal scale is approximately 370 to 1. In sections 2 and 19, which run almost west to east, a longitude scale with approximately the same relation to the depth scale has been used.

The bottom profiles are only schematic, constructed after a preliminary examination of the soundings, but in their main topographical features they are likely to prove fairly accurate.

The letters AC and STC above the sections mark the positions of the Antarctic and subtropical convergences.

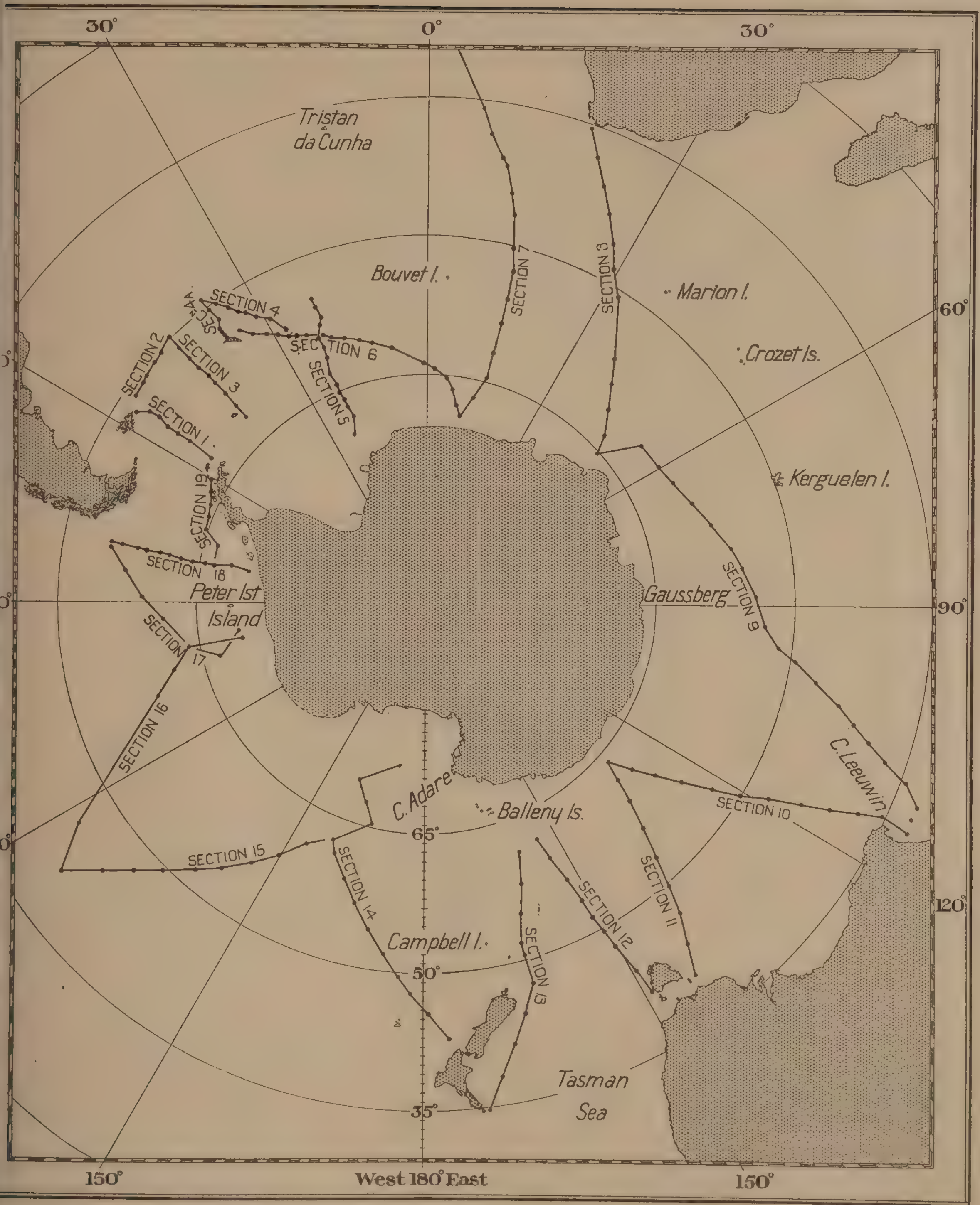
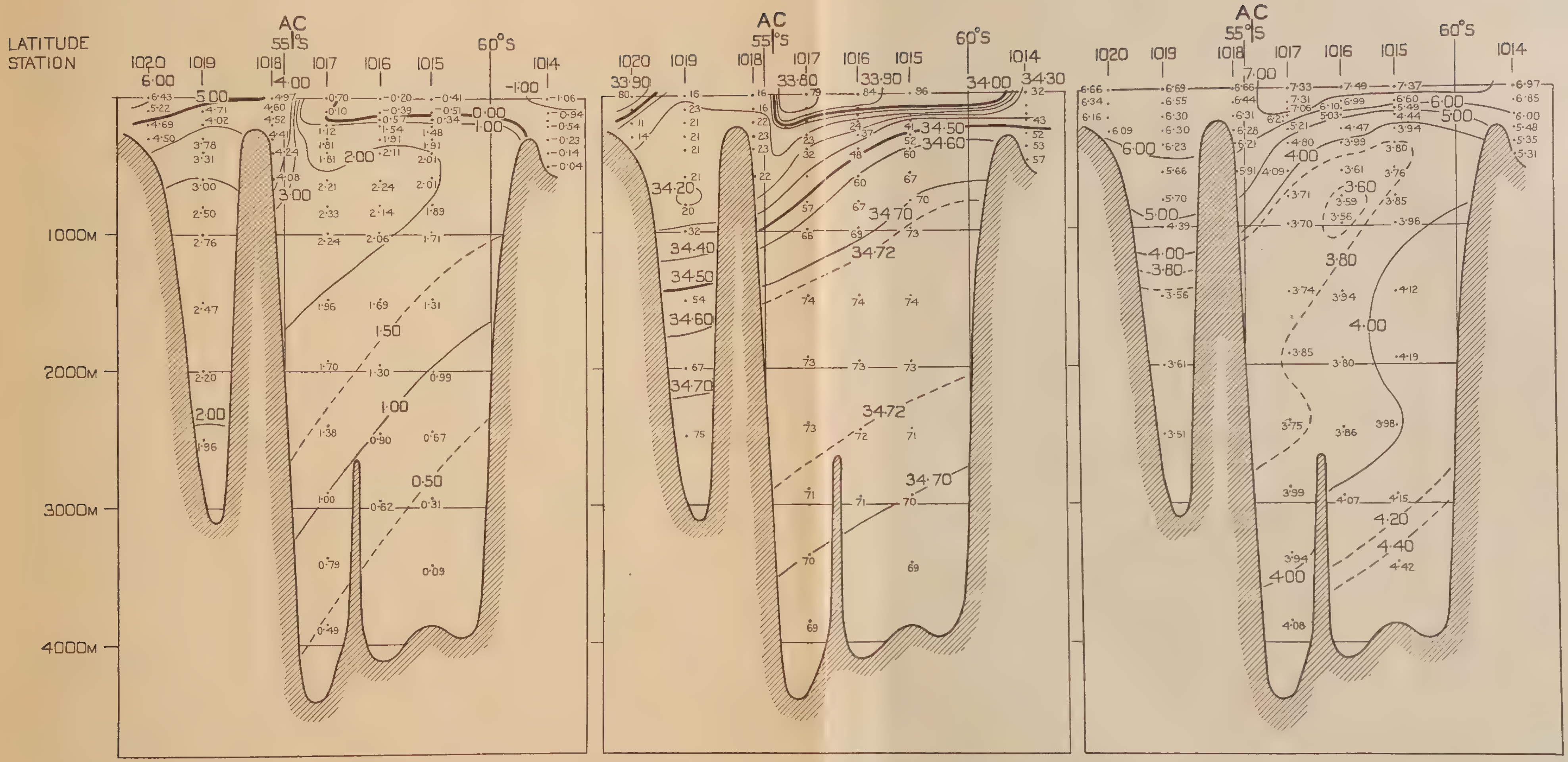
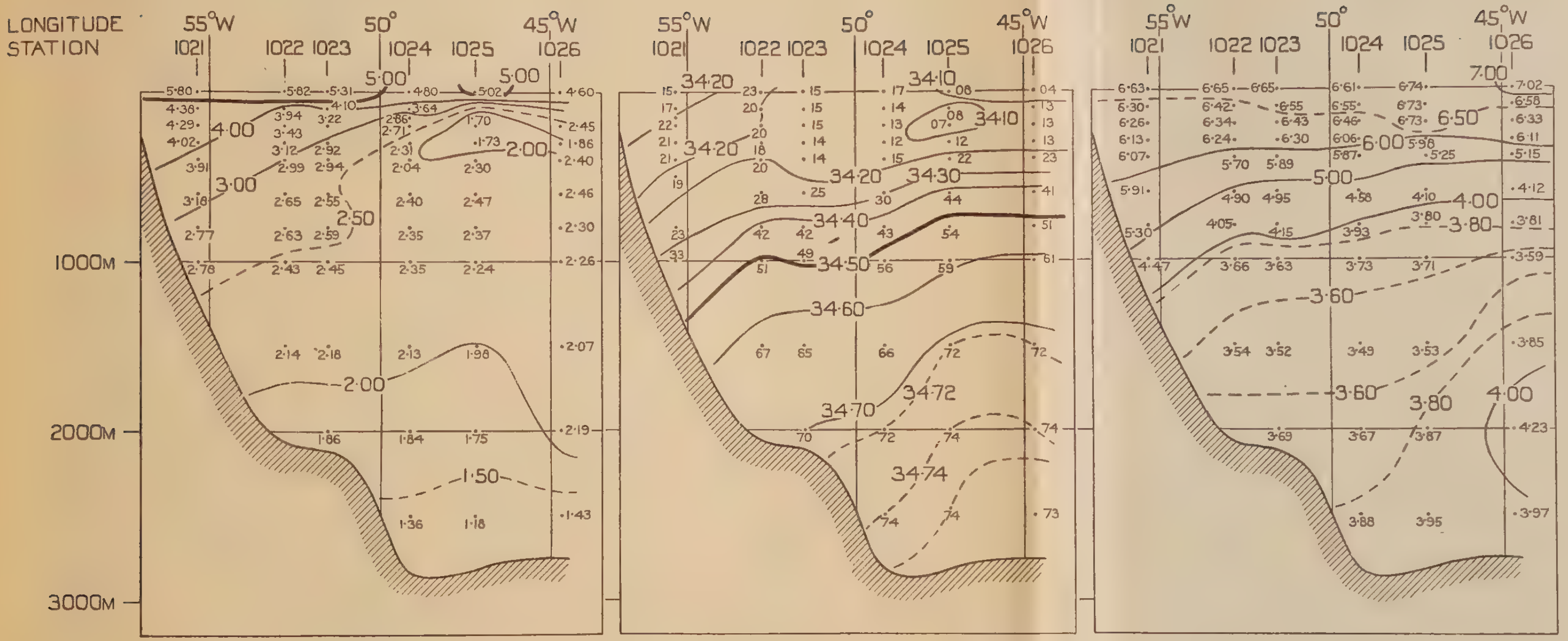

30°
0°
30°
Tristan da Cunha
Bouvet I.
SECTION 7
SECTION 3
Marion I.
60°
Crozet Is.
SECTION 4
SEC. 4A
SECTION 2
SECTION 3
SECTION 6
SECTION 5
SECTION 1
SECTION 19
Kerguelen I.
SECTION 18
Peter Ist Island
Gaussberg
SECTION 9
90°
SECTION 17
SECTION 16
C. Leeuwin
C. Adare
Balleny Is.
SECTION 10
65°
SECTION 15
SECTION 14
SECTION 11
SECTION 12
120°
Campbell I.
SECTION 13
50°
Tasman Sea
35°
150°
West 180° East
150°

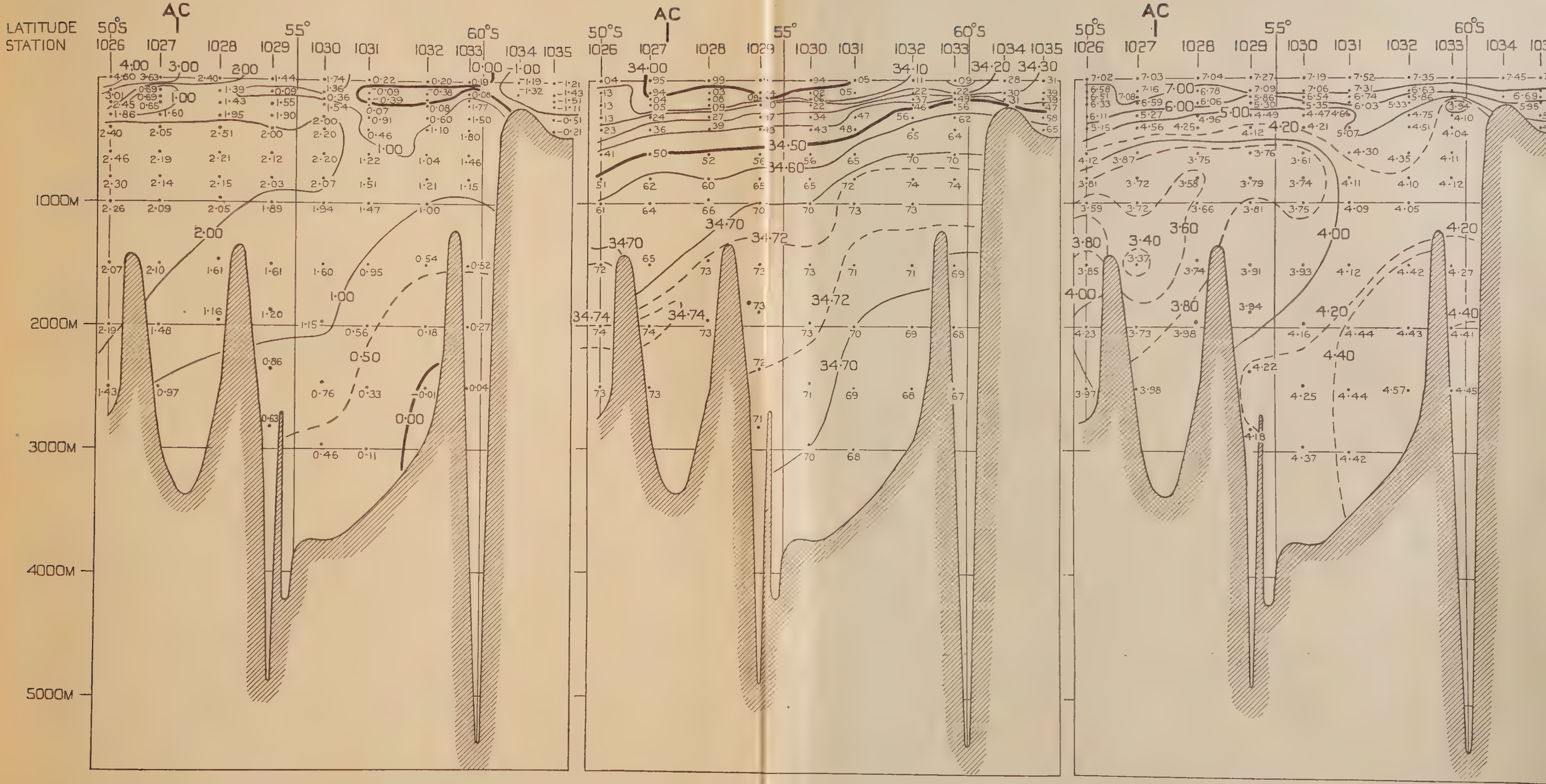
Chart of the Southern Ocean, showing the positions of sections 1–19.



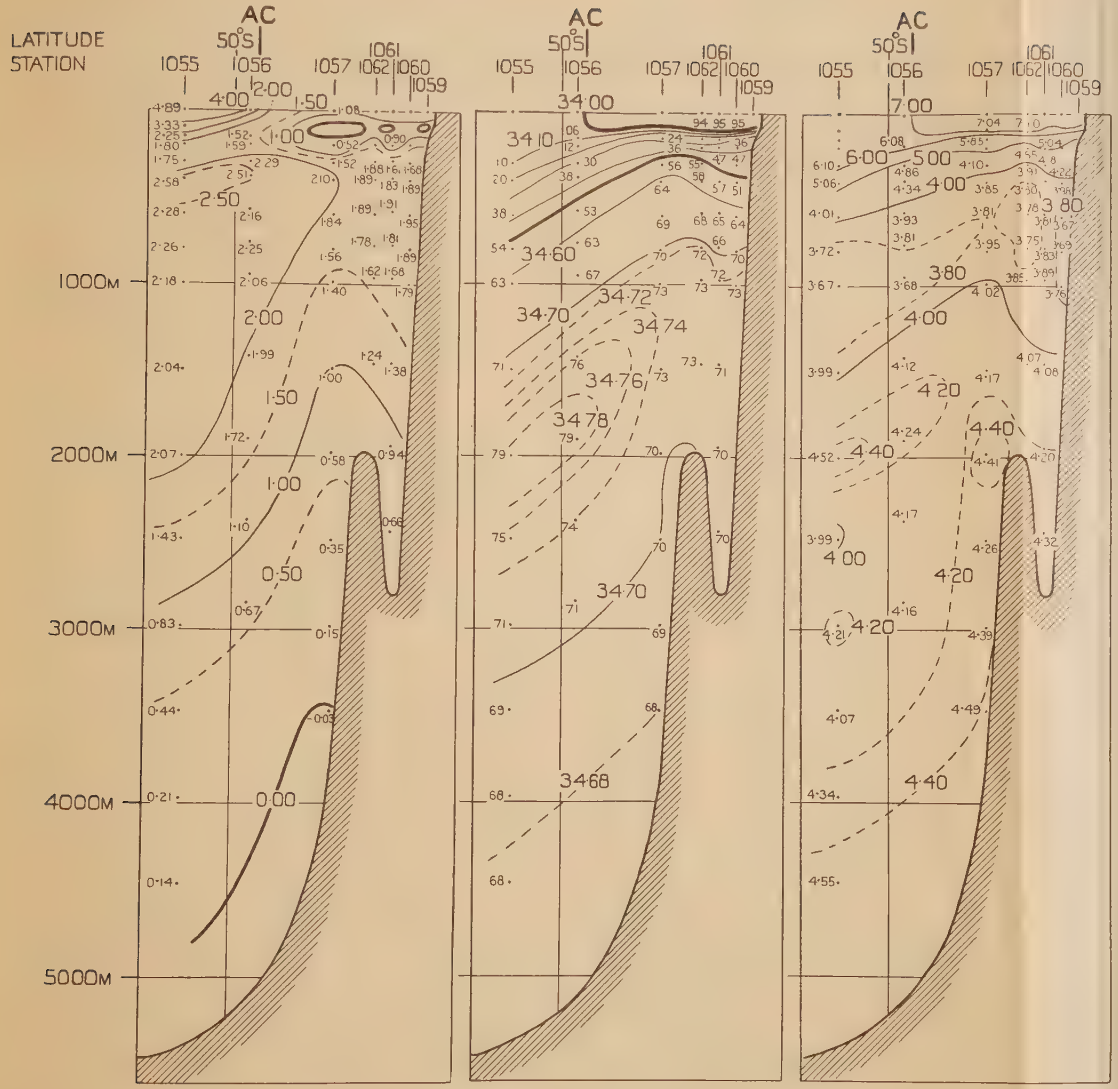
The distribution of temperature, salinity and oxygen content along section 1, from Elephant Island to the Falkland Islands. November 1932.



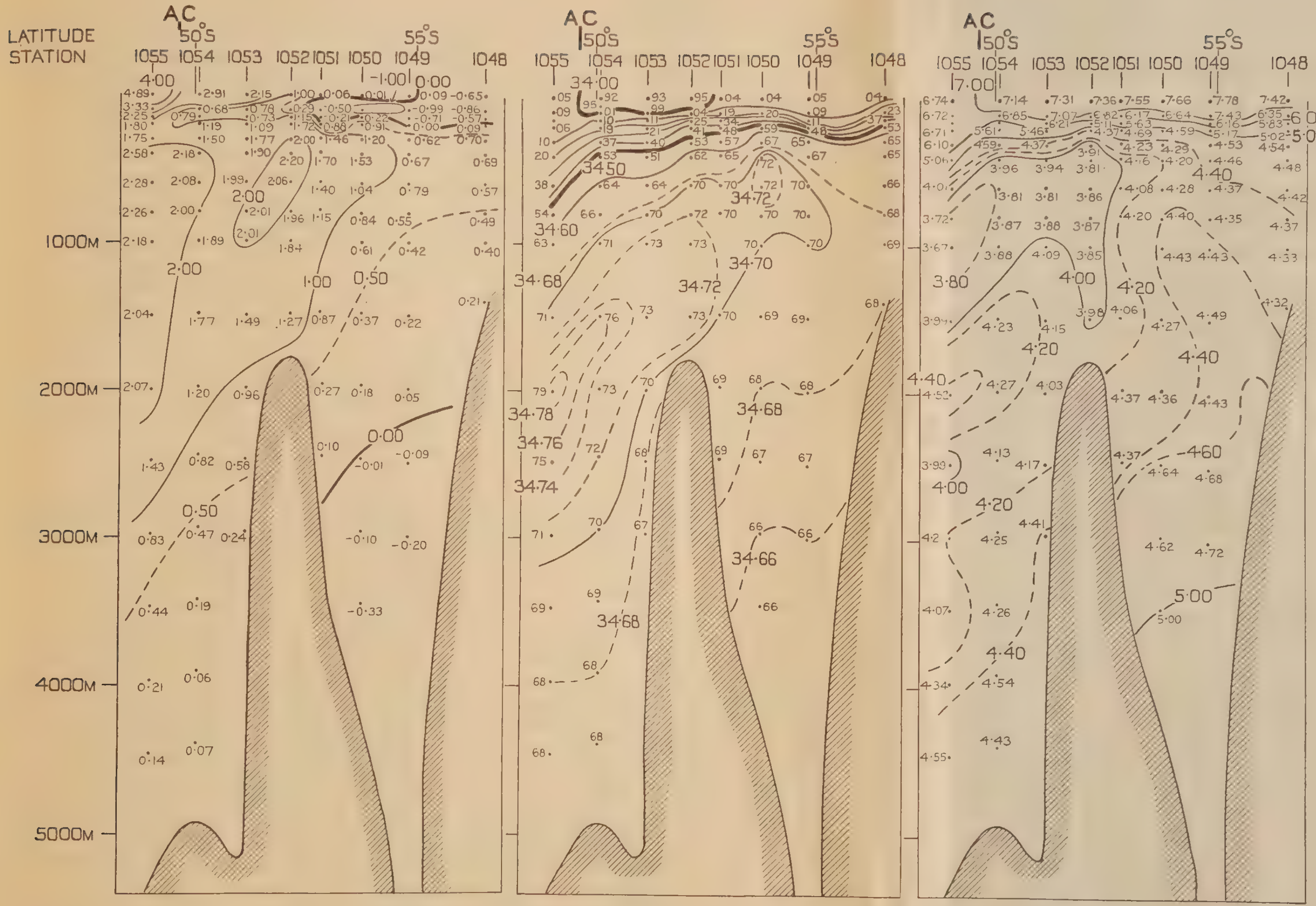
The distribution of temperature, salinity and oxygen content along section 2, 550 miles east-north-east of the Falkland Islands. November 1932.



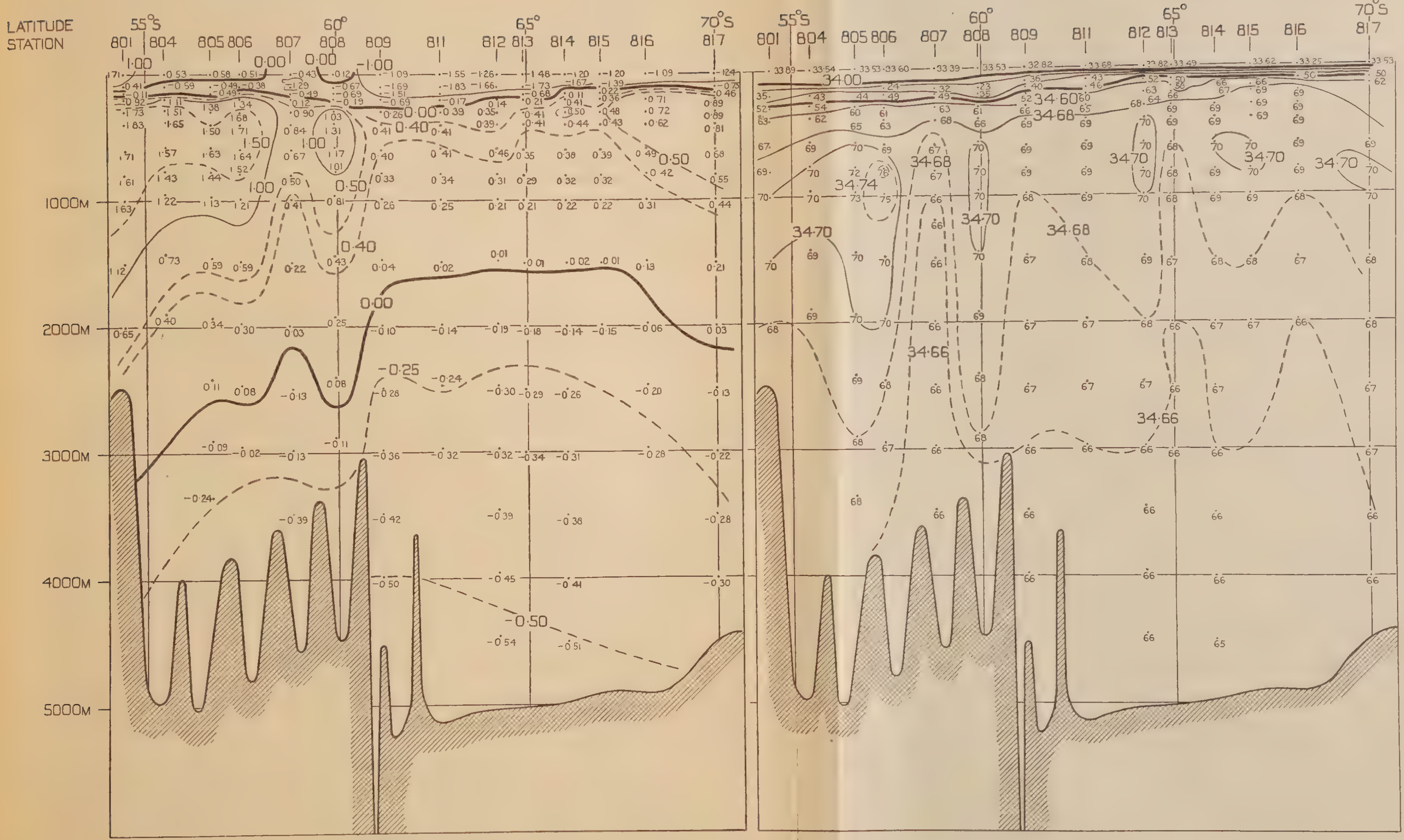
The distribution of temperature, salinity and oxygen content along section 3, from the end of section 2, 550 miles east-north-east of the Falkland Islands, to the South Orkney Islands and the northern part of the Weddell Sea. November–December 1932.



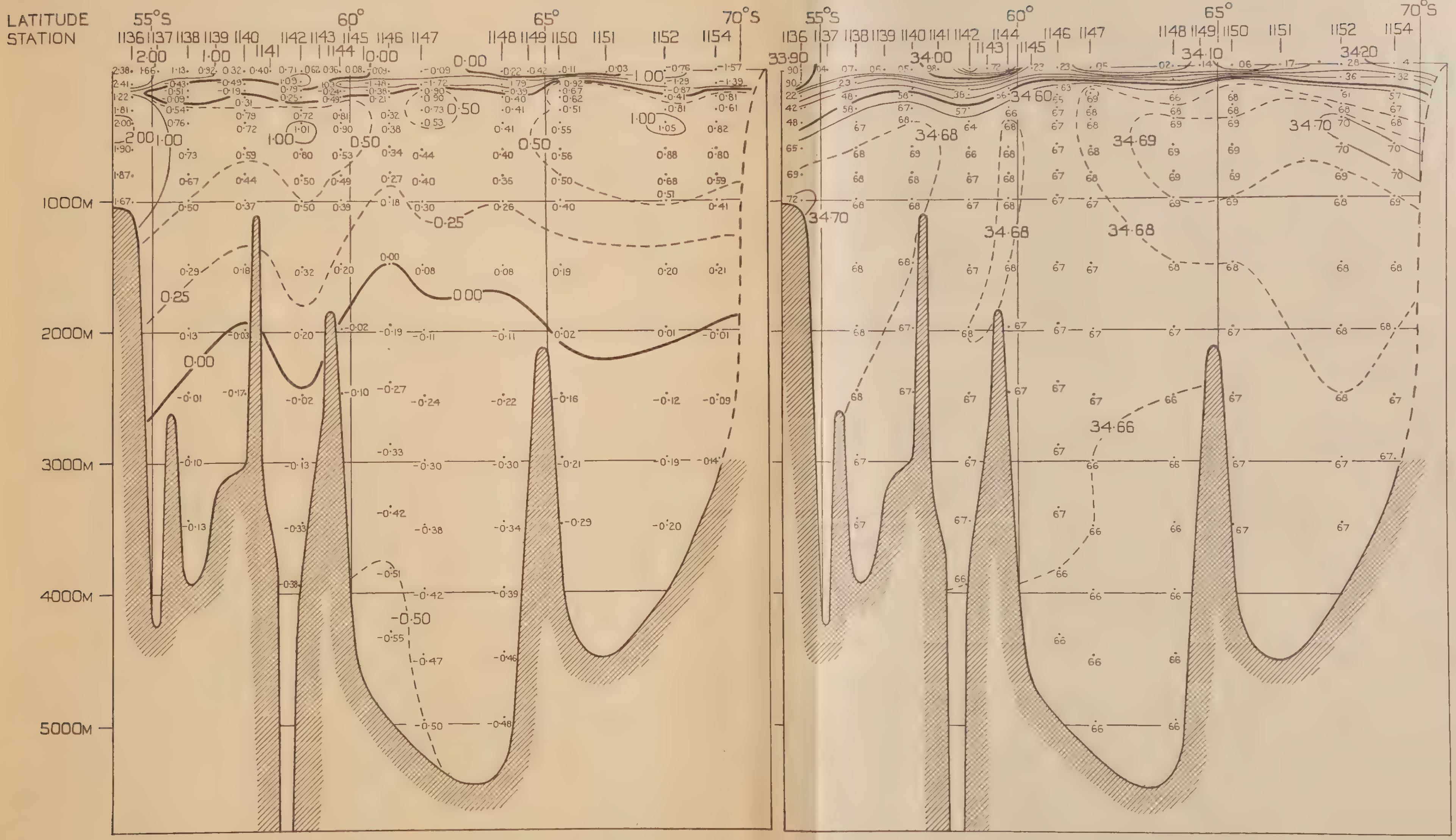
The distribution of temperature, salinity and oxygen content along section 4 *a*, from South Georgia to a point 300 miles to the northward. December 1932.



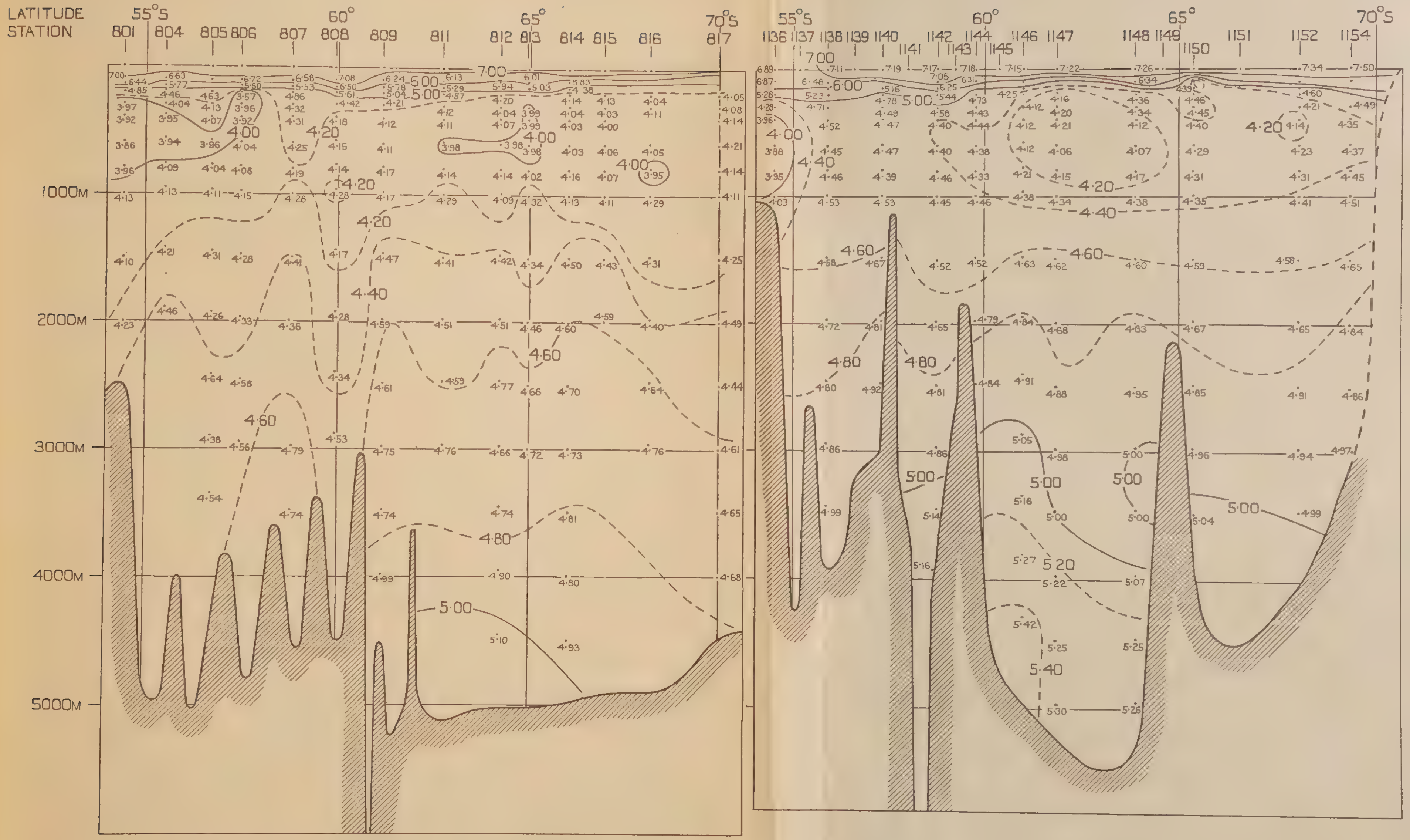
The distribution of temperature, salinity and oxygen content along section 4 from the northern end of section 4 *a*, 300 miles north of South Georgia, to the northern end of the South Sandwich Group. December 1932.



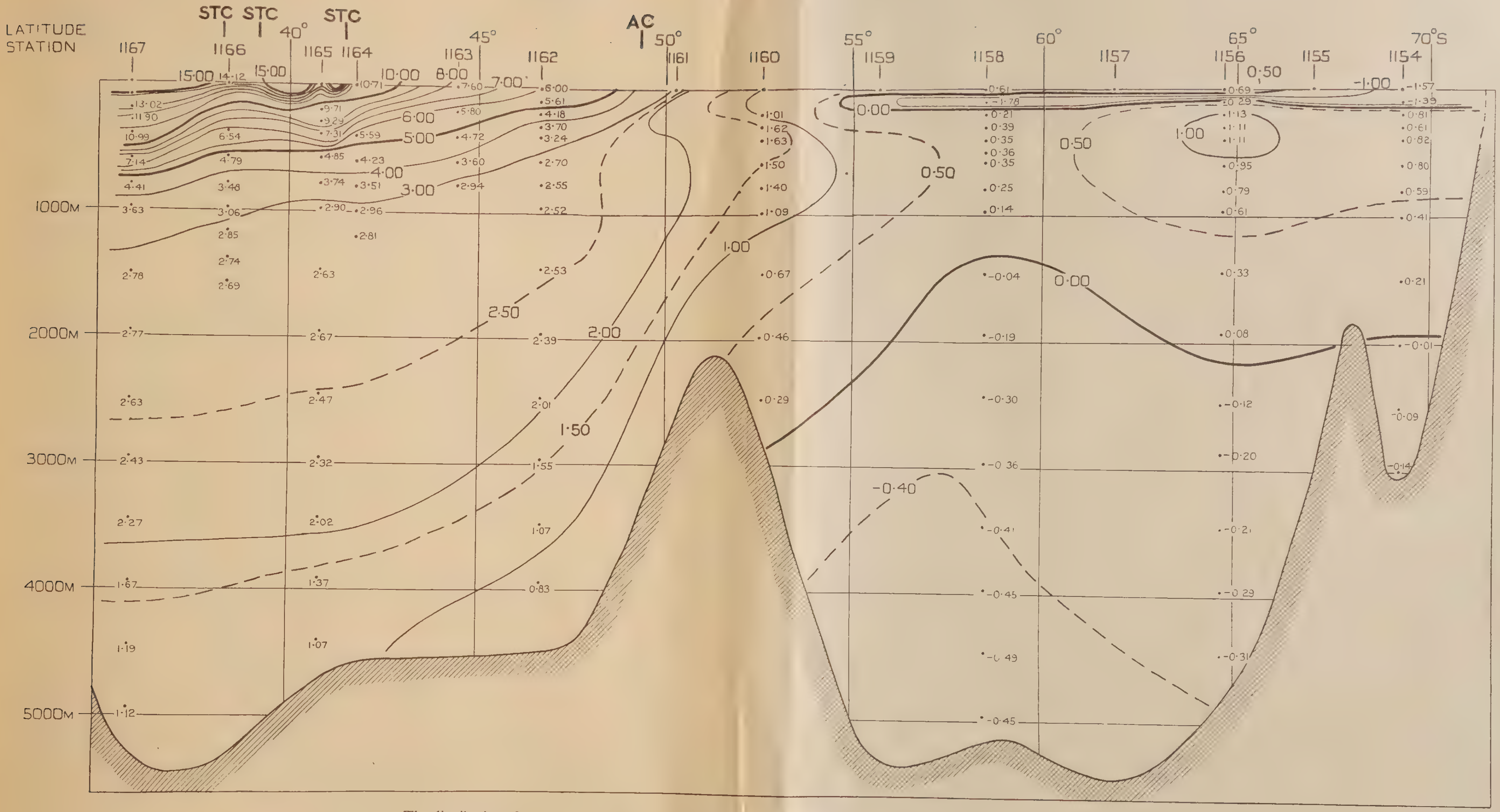
The distribution of temperature and salinity along section 5, a longitudinal section from 55° 30′ S to 69° 59′ S in 21–24° W. January 1932.



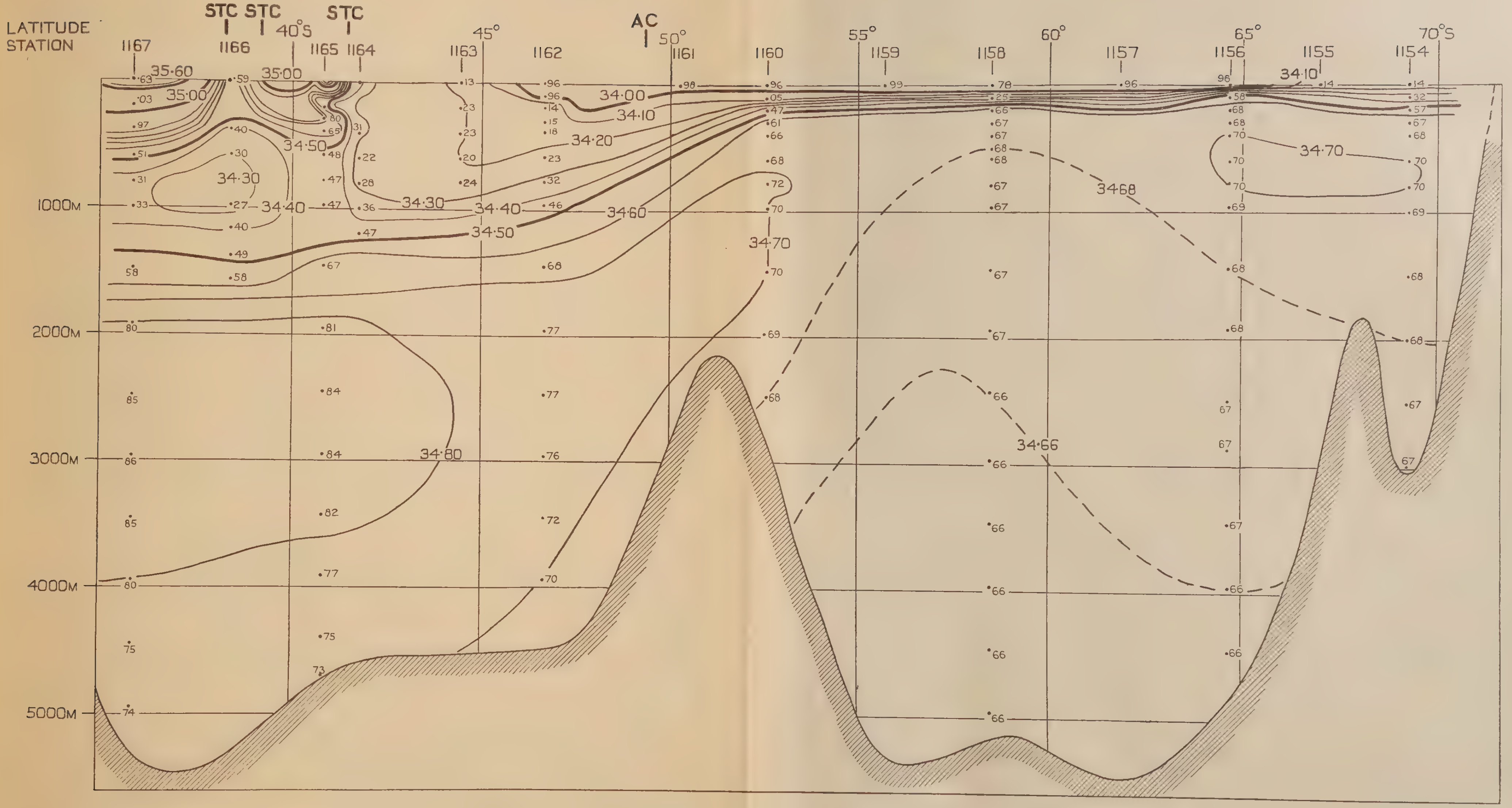
The distribution of temperature and salinity along section 6 from South Georgia across the Scotia Sea and the Atlantic Antarctic basin to 69° 20′ S, 9° 34′ E. March 1933.



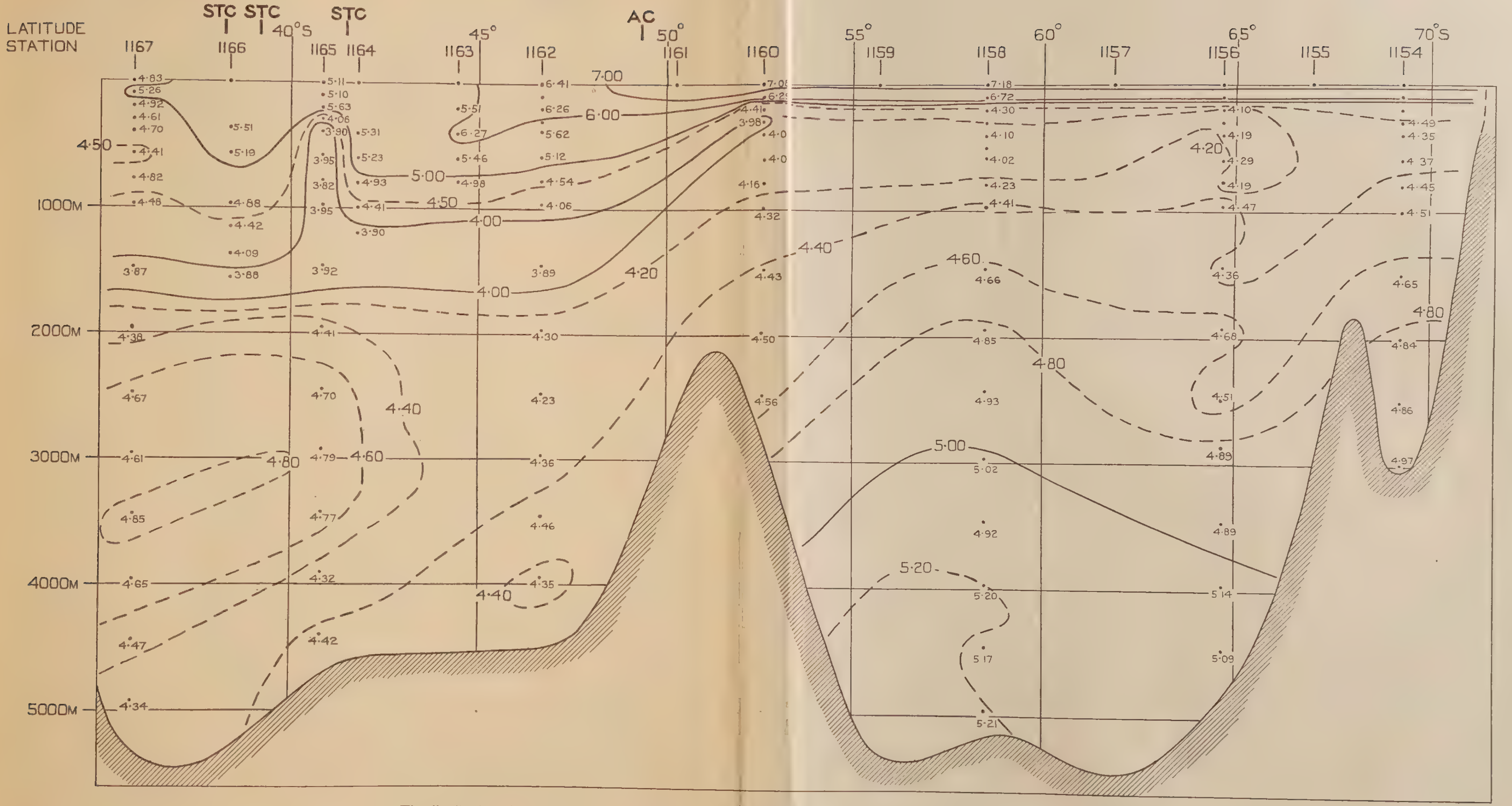
The distribution of oxygen content along section 5, a longitudinal section from 55° 30′ S to 69° 59′ S in 21–24° W, January 1932, and section 6, from South Georgia across the Scotia Sea and the Atlantic Antarctic basin to 69° 20′ S, 9° 34′ E, March 1933.



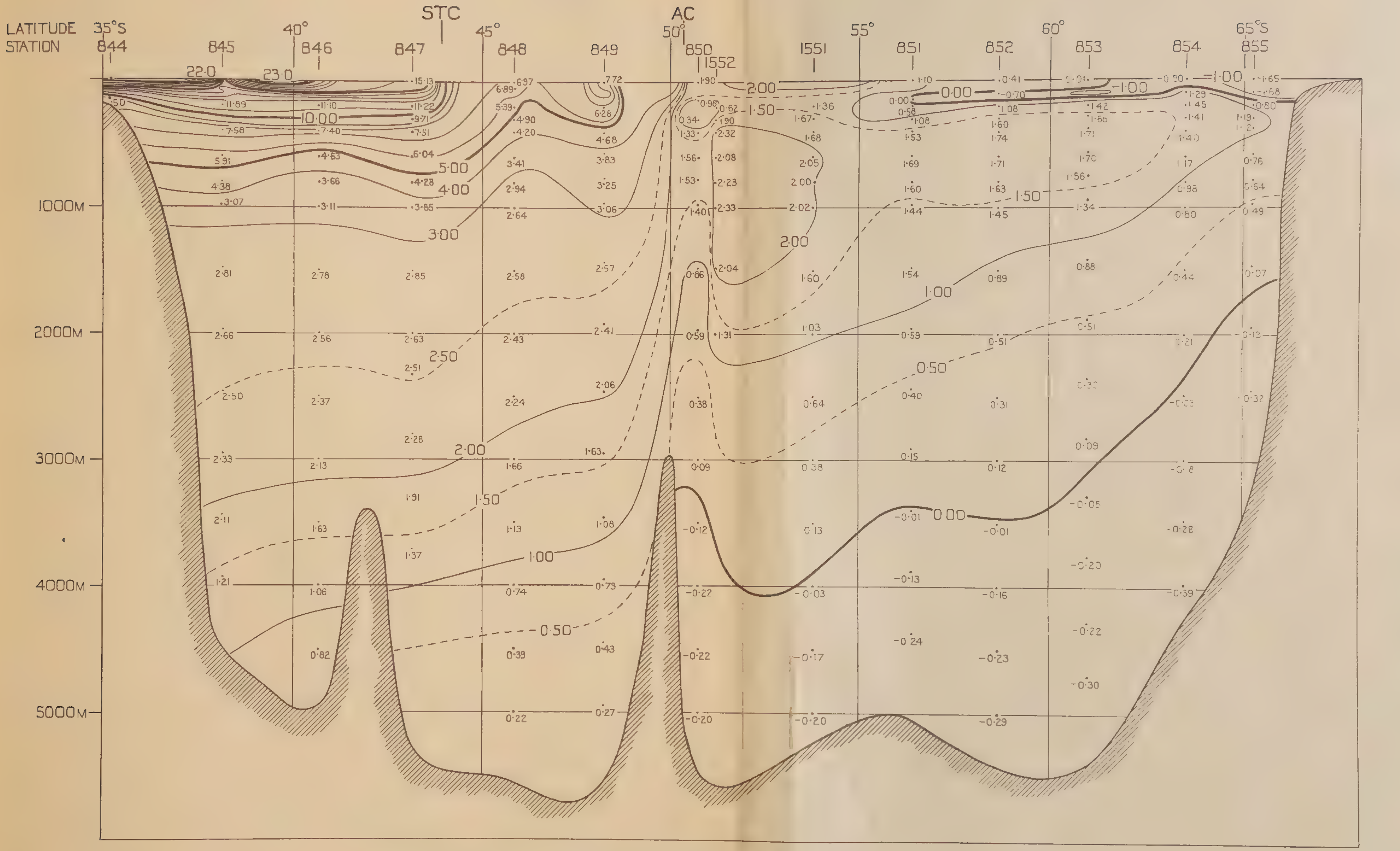
The distribution of temperature along section 7, a longitudinal section from 69° 20′ S to 36° 01′ S in 6–15° E. March–April 1933.



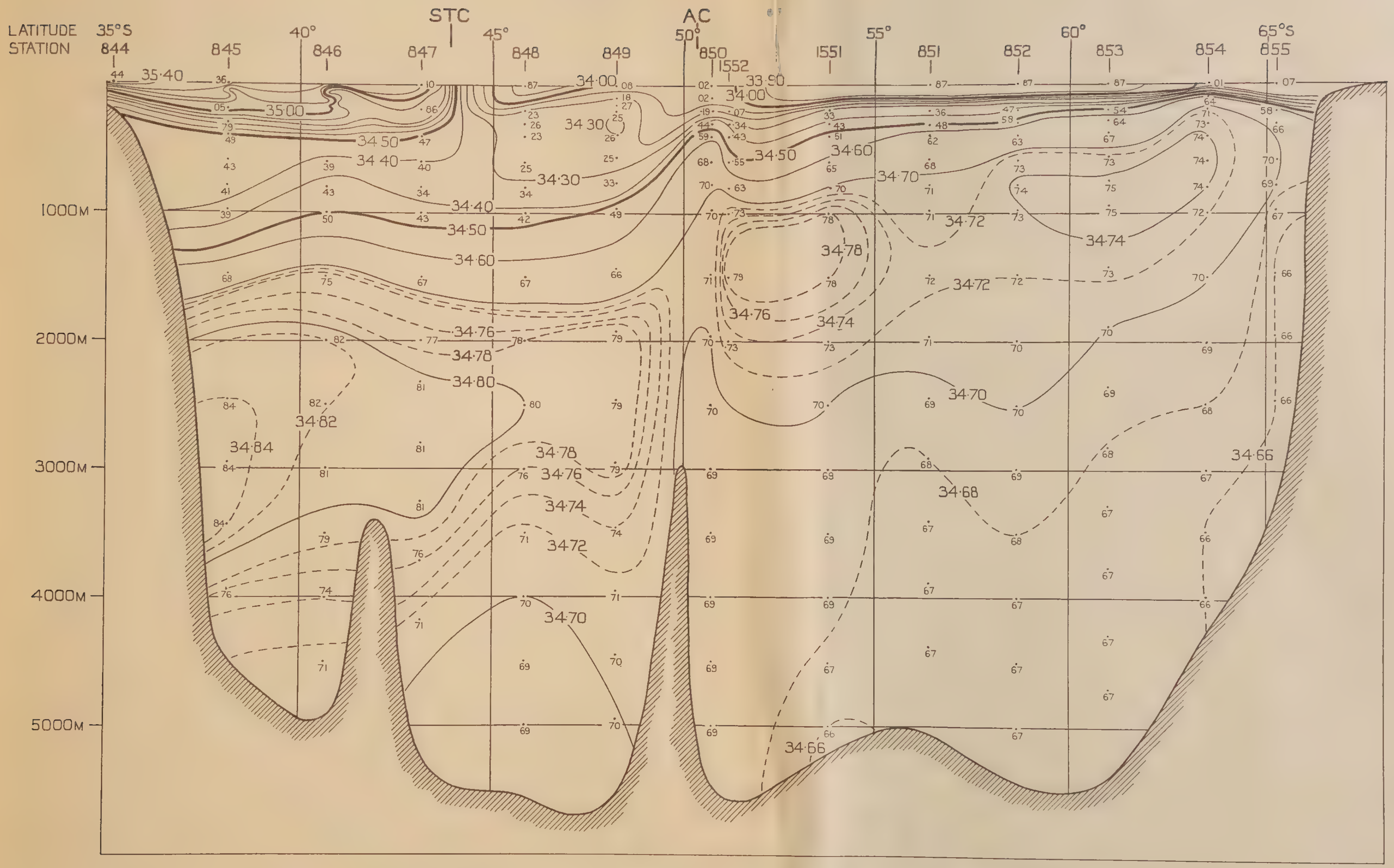
The distribution of salinity along section 7, a longitudinal section from 69° 20′ S to 36° 01′ S in 6–15° E. March–April 1933.



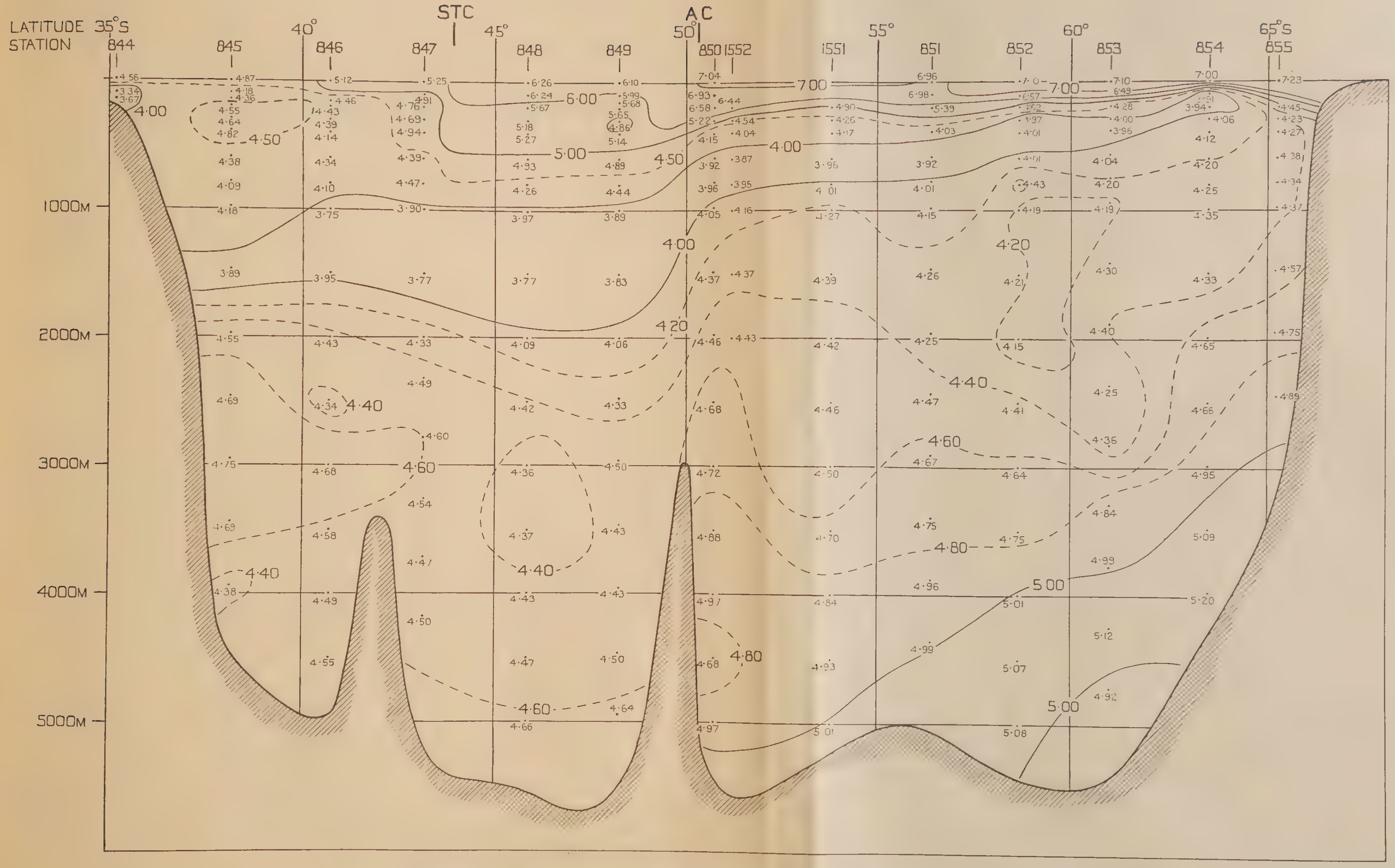
The distribution of oxygen content along section 7, a longitudinal section from 69° 20′ S to 36° 01′ S in 6–15° E. March–April 1933.



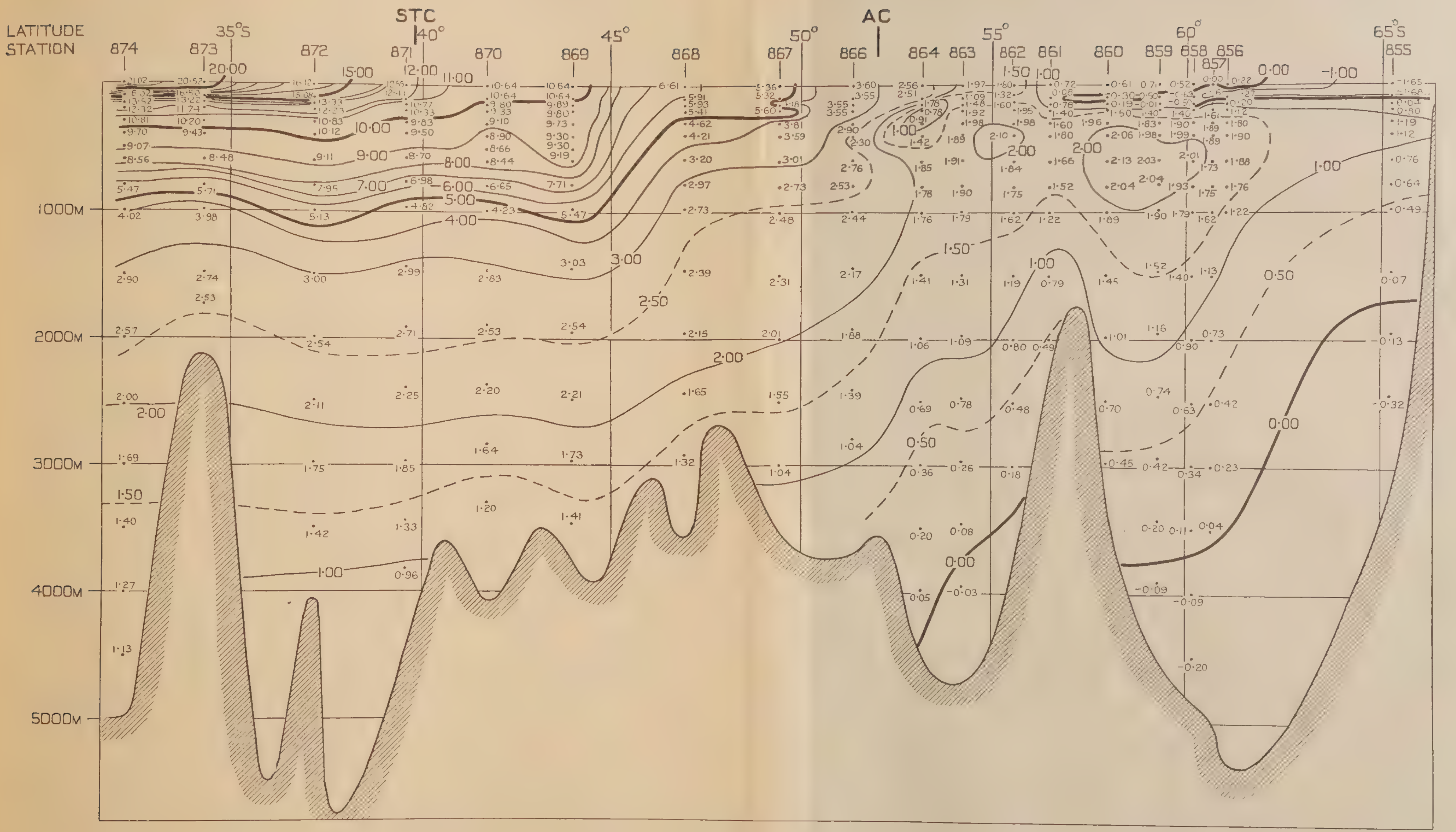
The distribution of temperature along section 8 from the Cape of Good Hope to Enderby Land. April 1932.



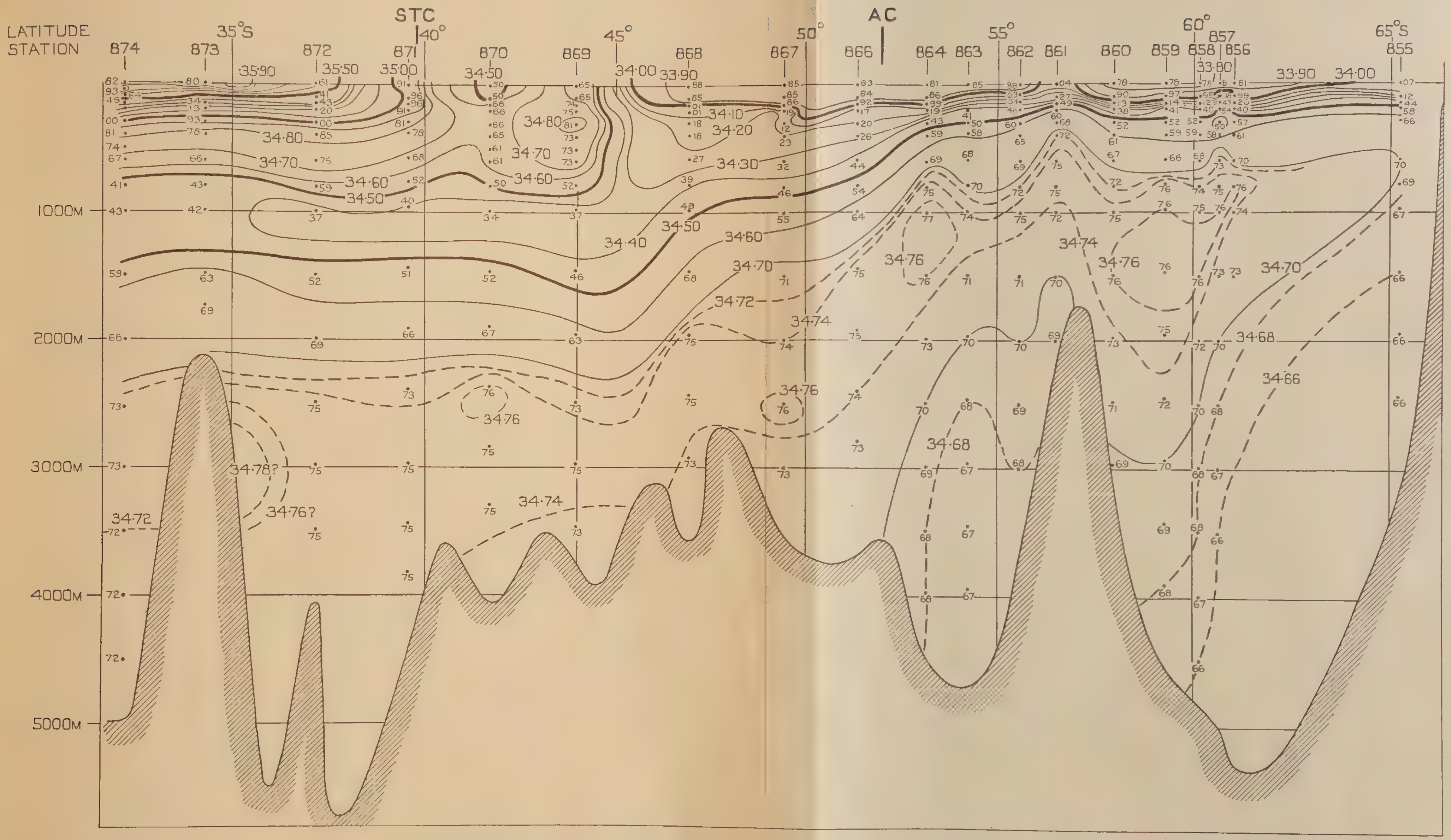
The distribution of salinity along section 8 from the Cape of Good Hope to Enderby Land. April 1932.



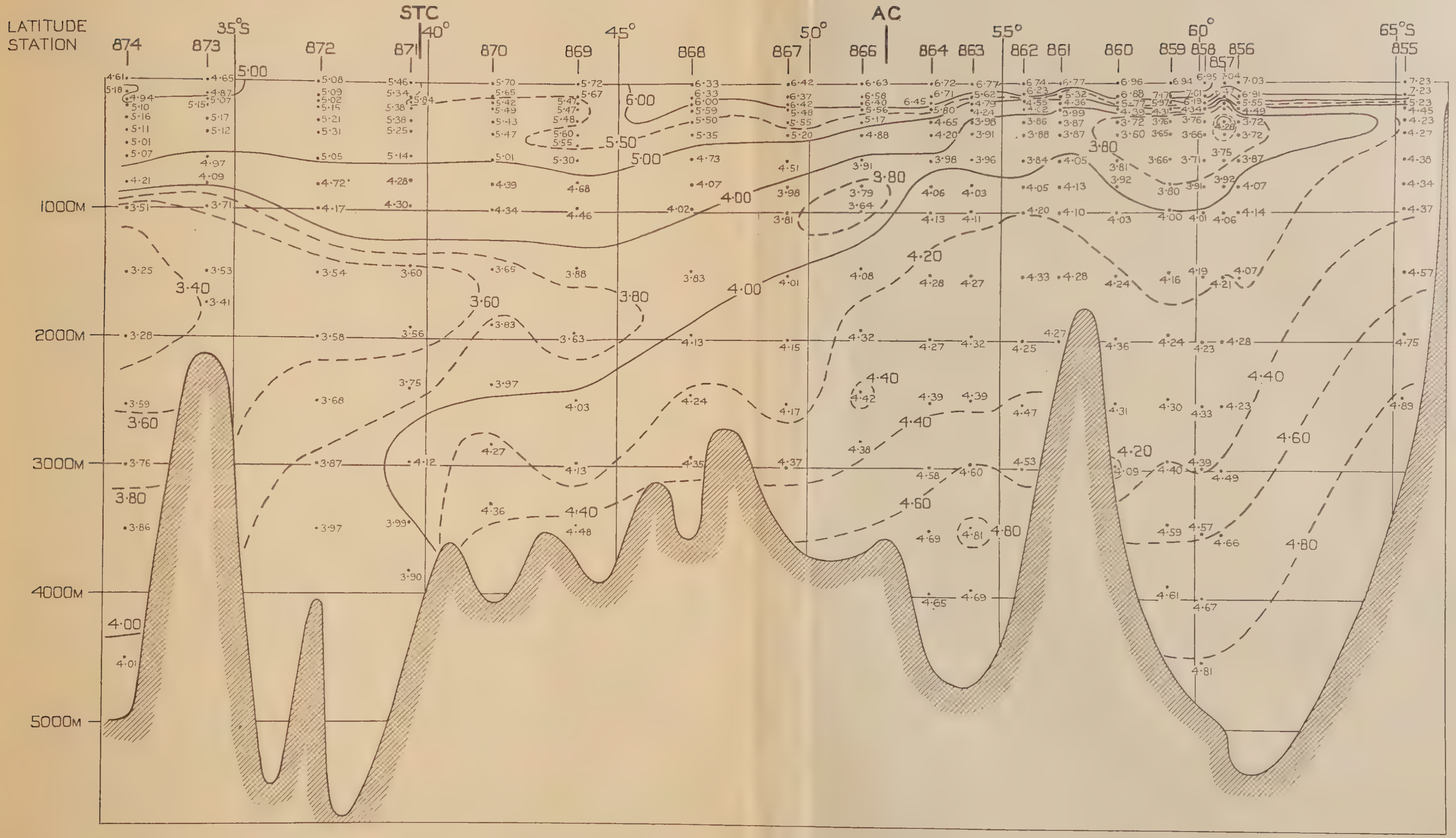
The distribution of oxygen content along section 8 from the Cape of Good Hope to Enderby Land. April 1932.



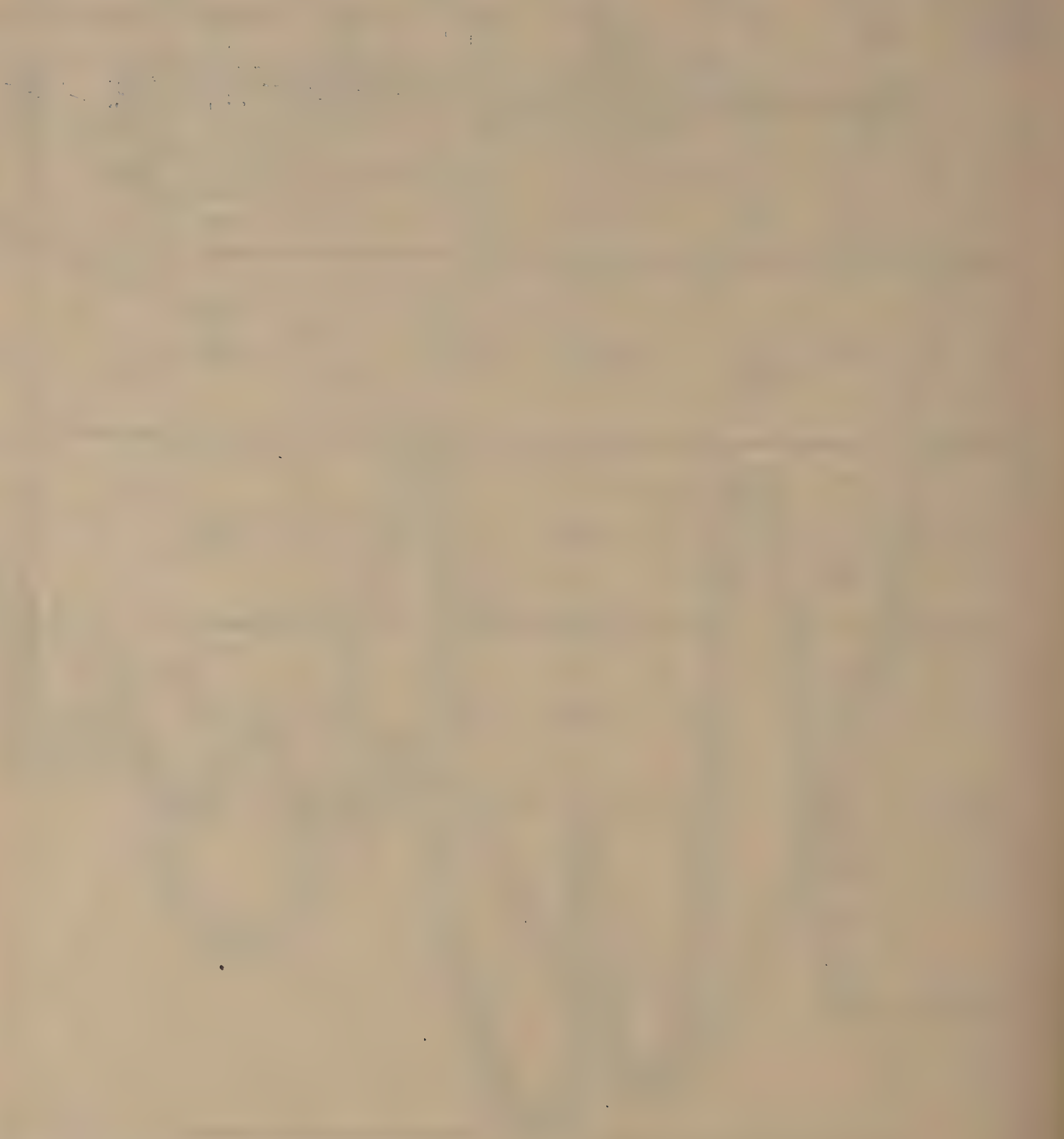
The distribution of temperature along section 9 from Enderby Land to Fremantle, Western Australia. April–May 1932.

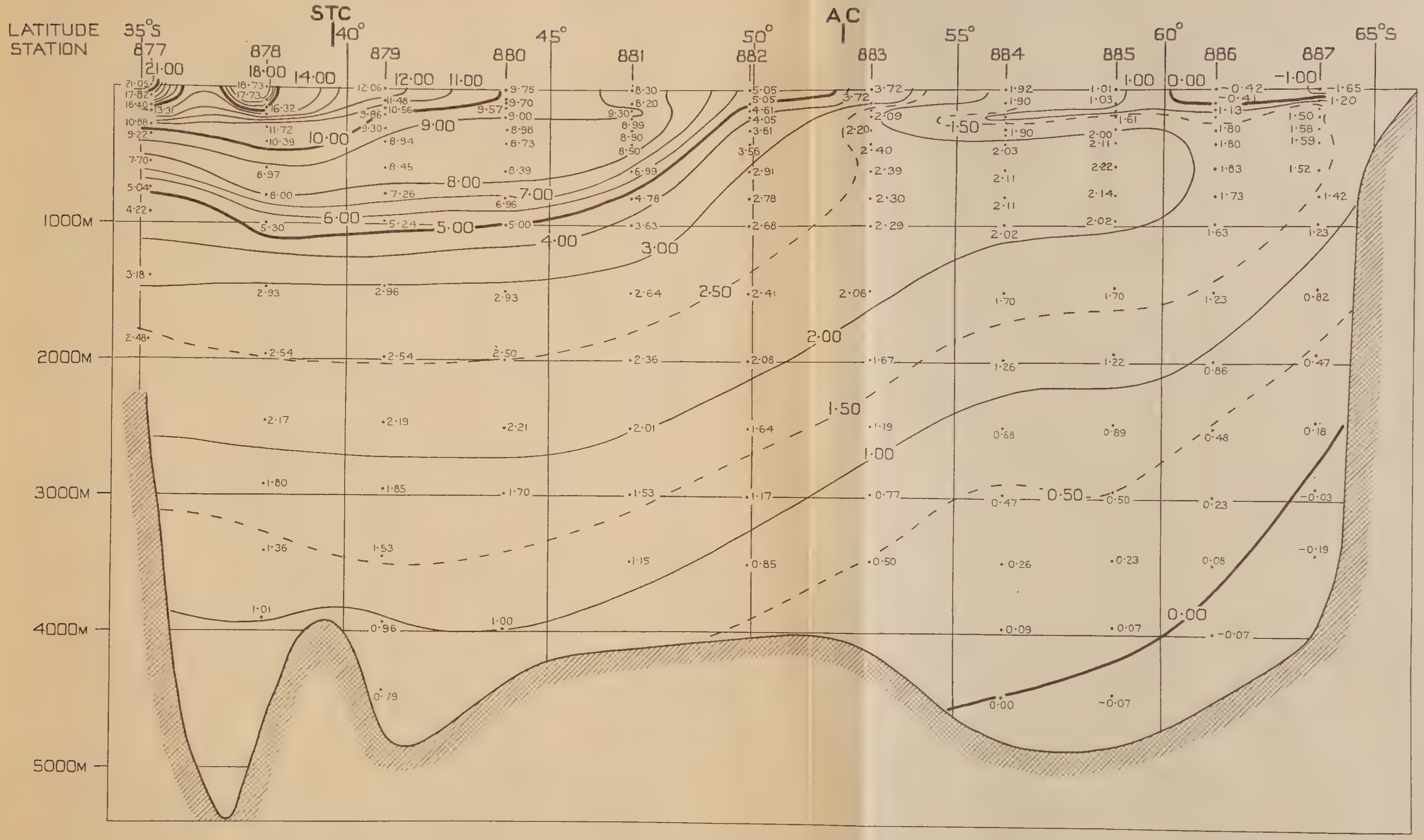


The distribution of salinity along section 9 from Enderby Land to Fremantle, Western Australia. April–May 1932.

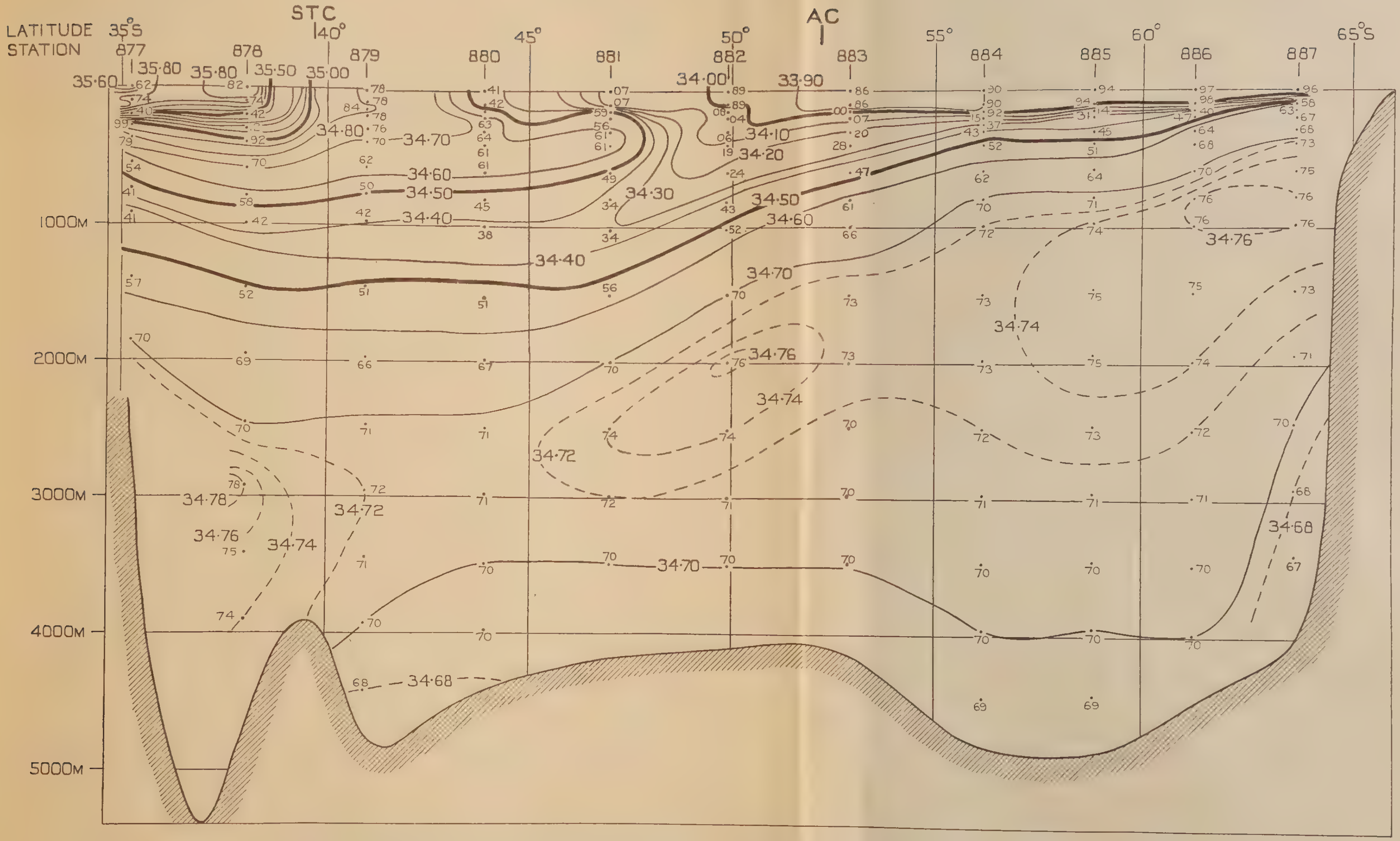


The distribution of oxygen content along section 9 from Enderby Land to Fremantle, Western Australia. April–May 1932.

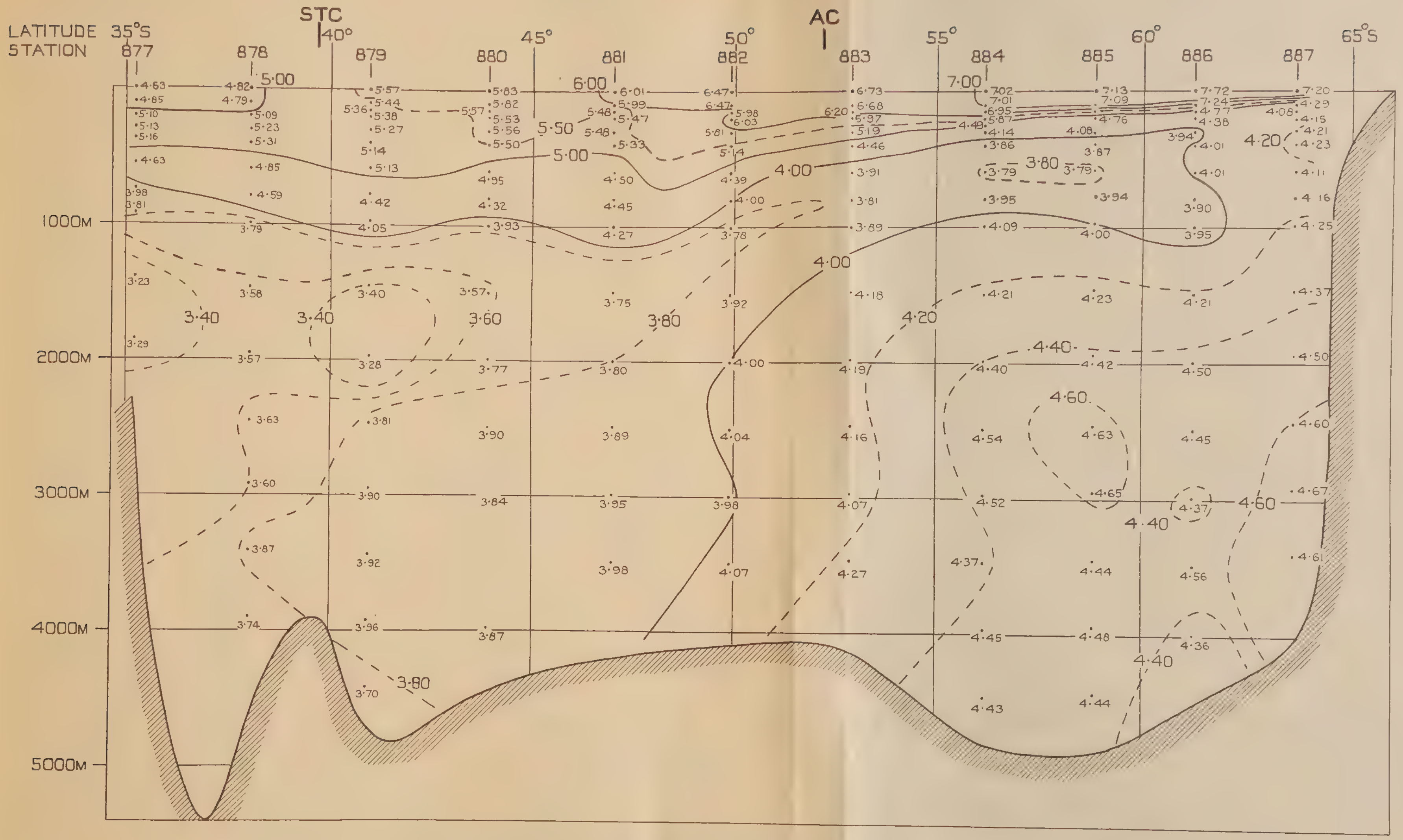




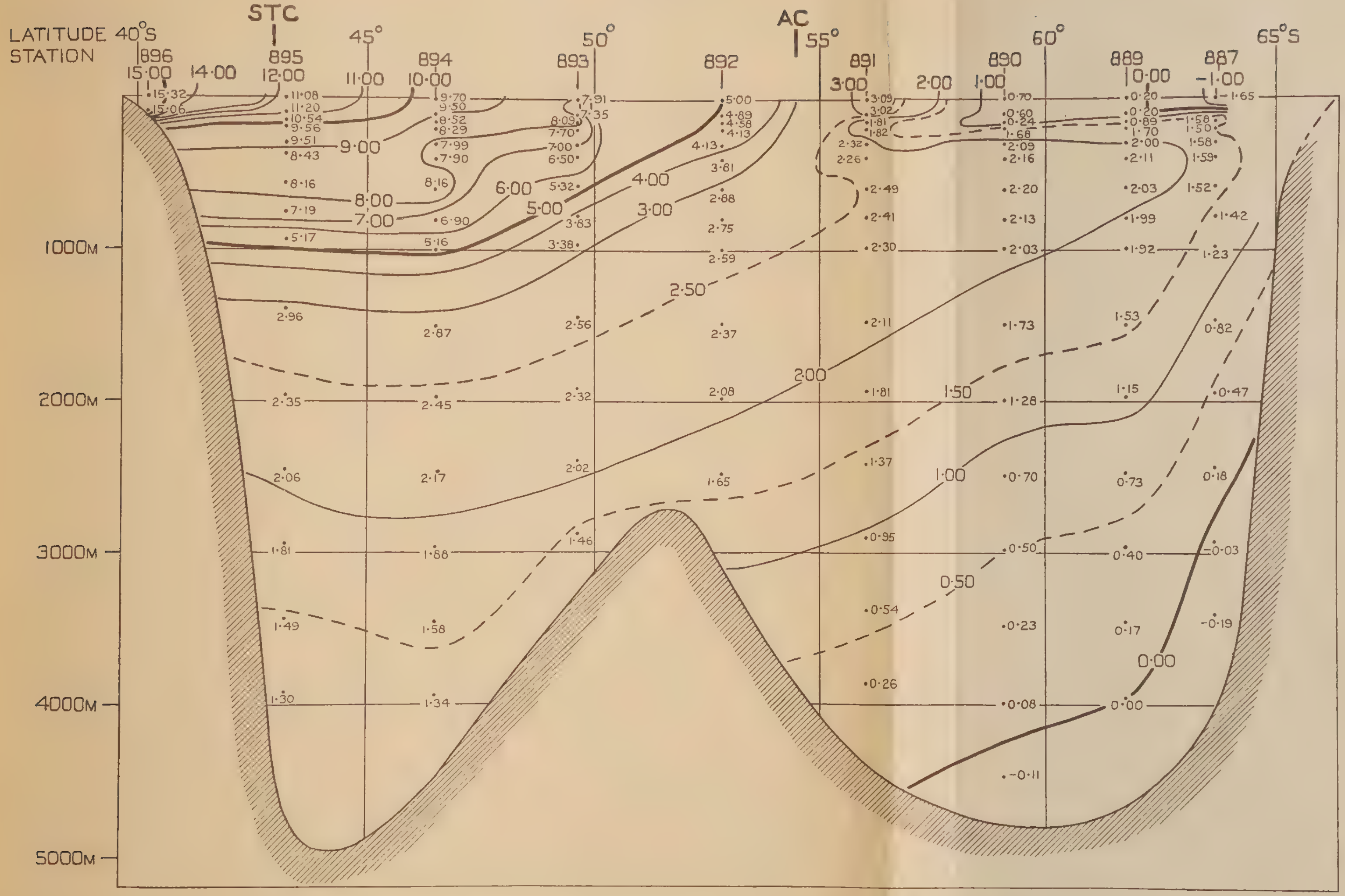
The distribution of temperature along section 10 from Cape Leeuwin, Western Australia, to the ice-edge south of Australia in 63° 41′ S, 130° 07′ E. May 1932.



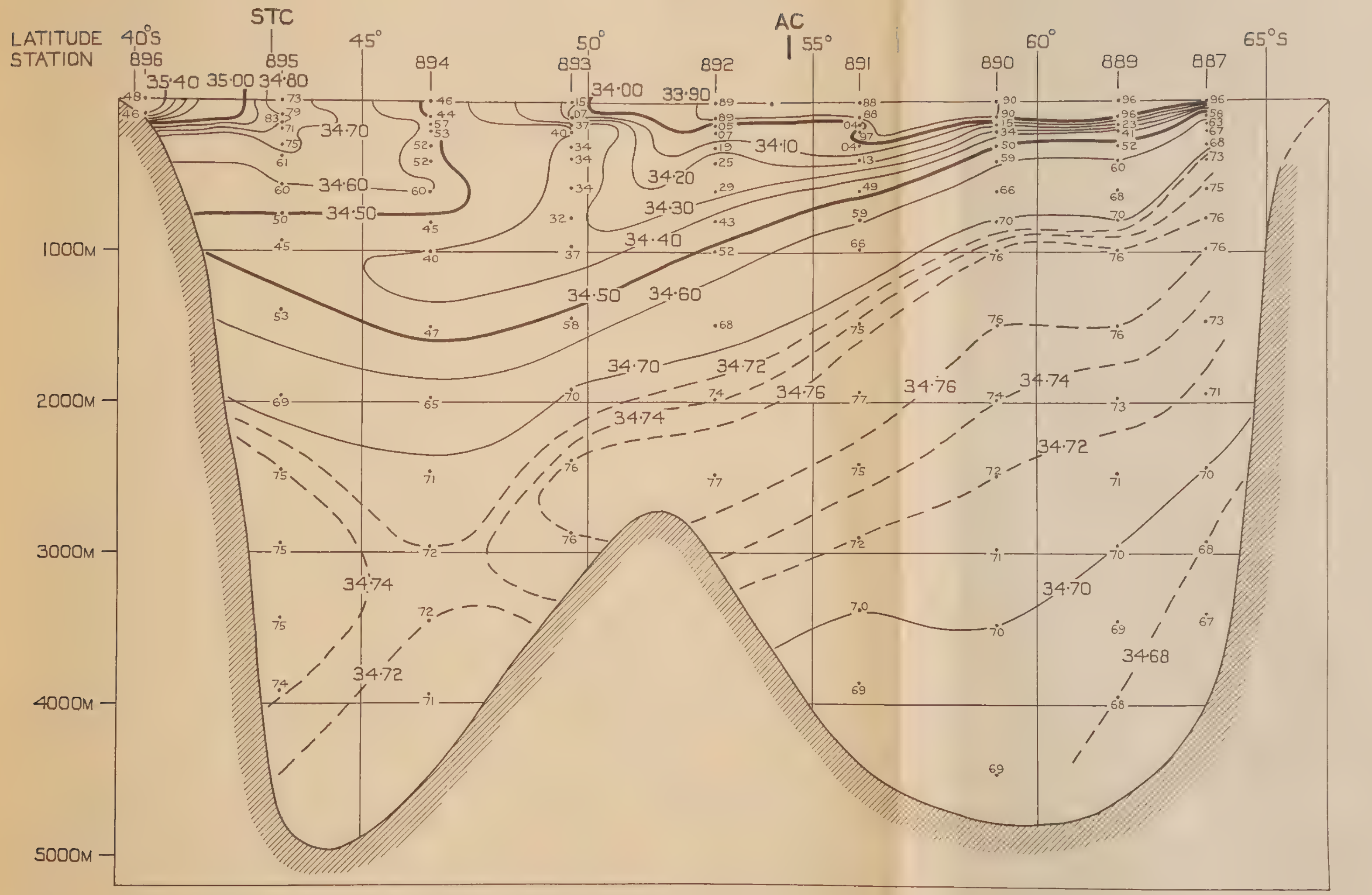
The distribution of salinity along section 10 from Cape Leeuwin, Western Australia, to the ice-edge south of Australia in 63° 41′ S, 130° 07′ E. May 1932.



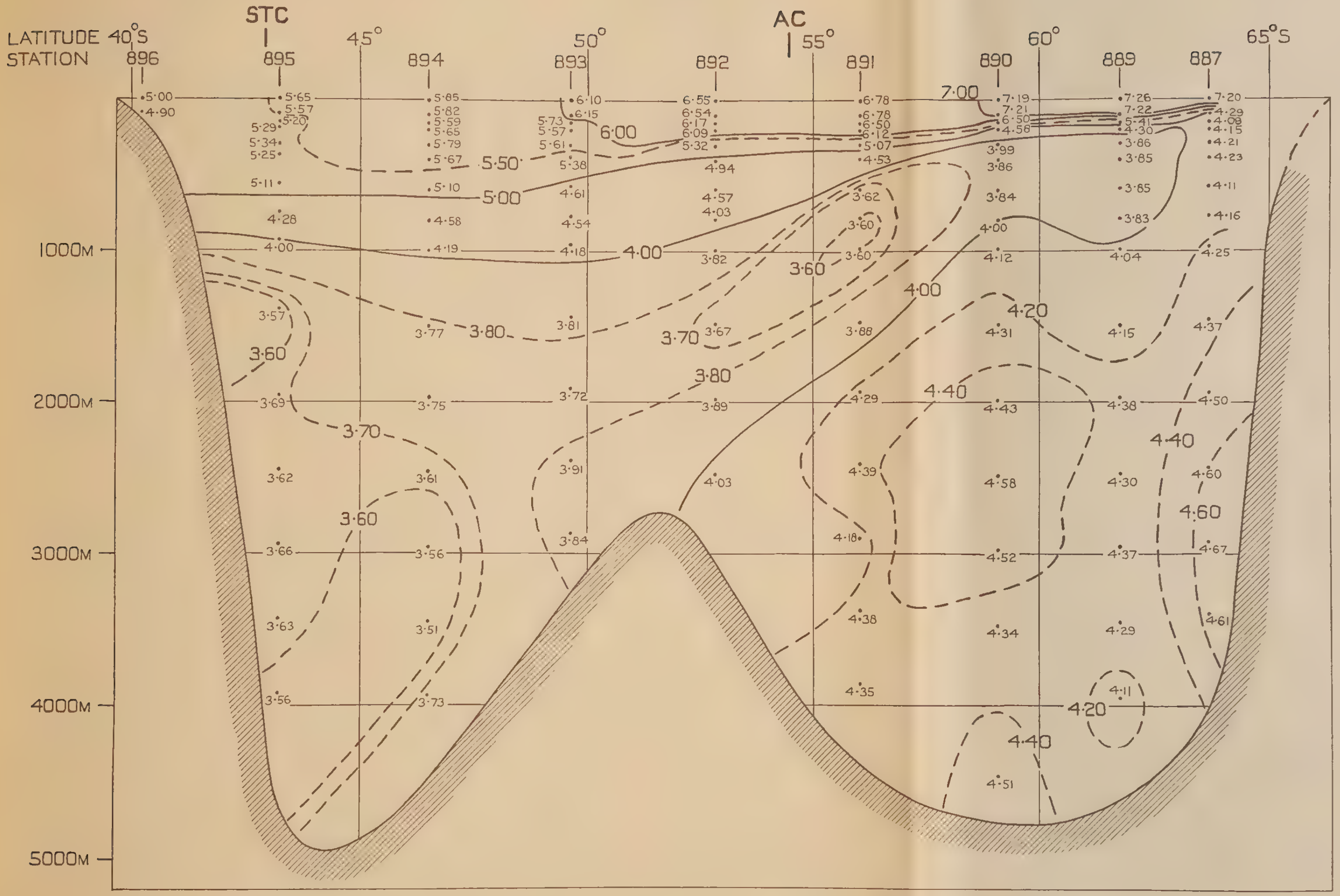
The distribution of oxygen content along section 10 from Cape Leeuwin, Western Australia, to the ice-edge south of Australia in 63° 41′ S, 130° 07′ E. May 1932.



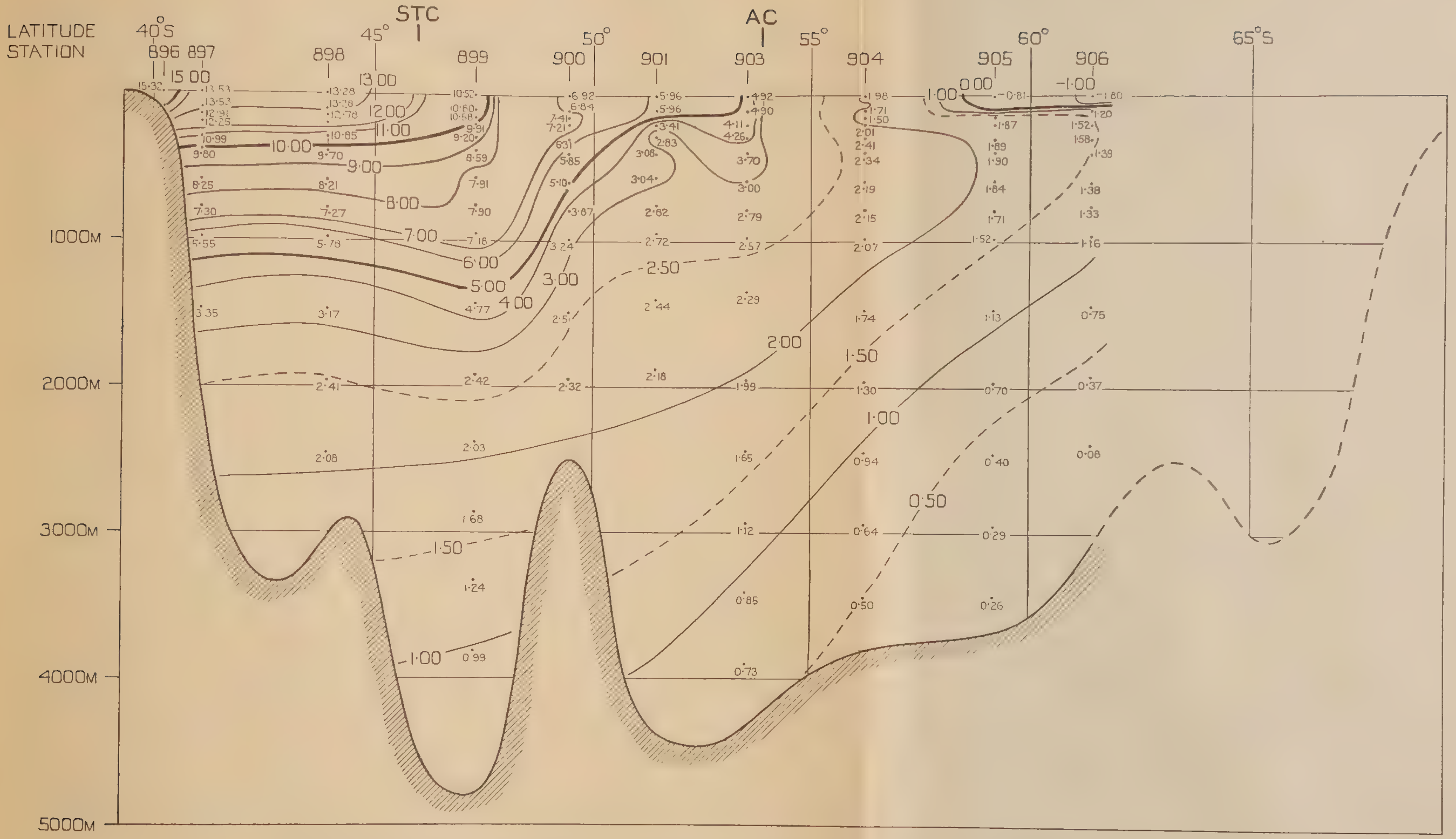
The distribution of temperature along section 11 from the ice-edge in 63° 41′ S, 130° 07′ E, south of Australia, to Melbourne, Victoria. May–June 1932.



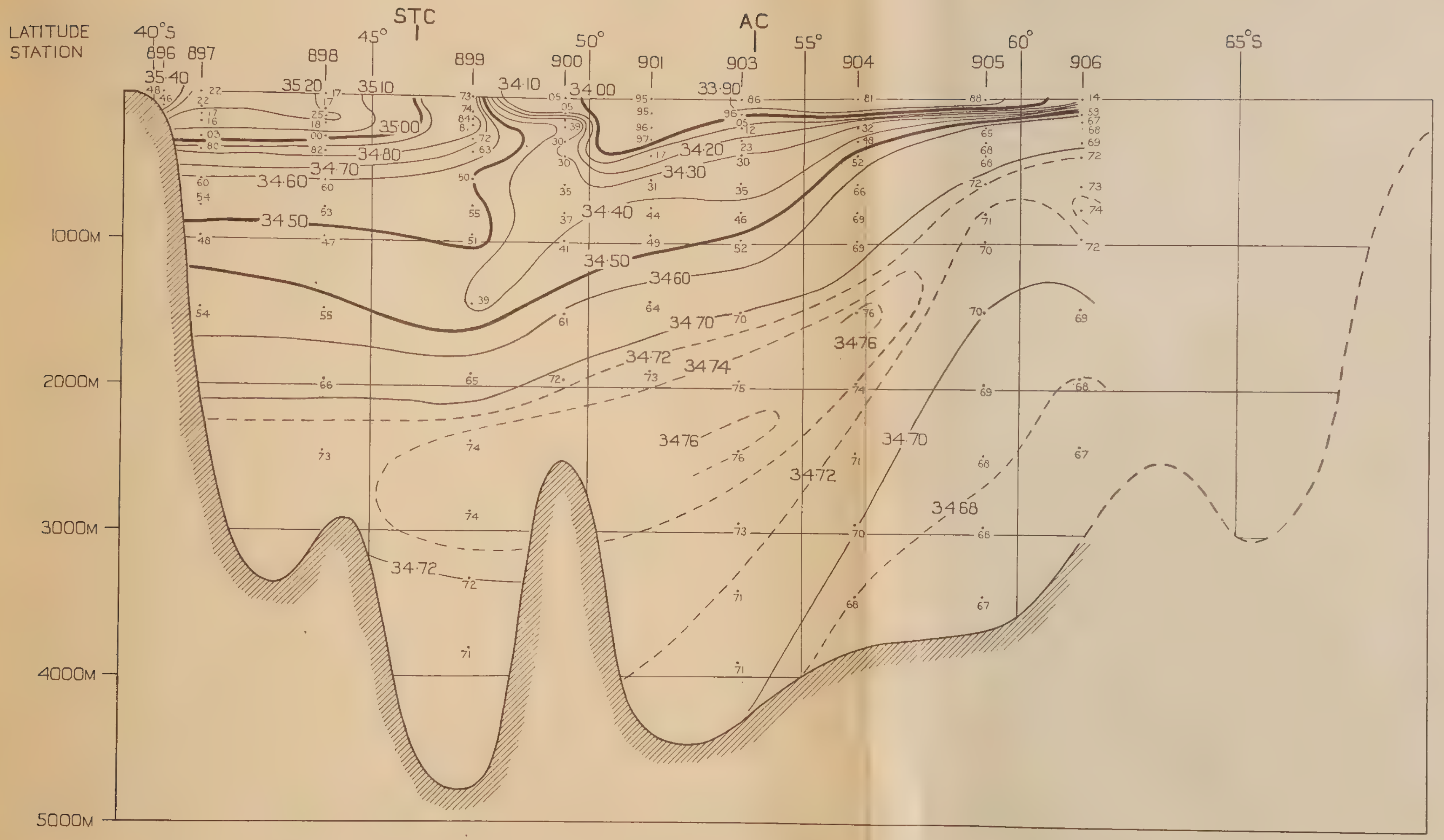
The distribution of salinity along section 11 from the ice-edge in 63° 41′ S, 130° 07′ E, south of Australia, to Melbourne, Victoria. May–June 1932.



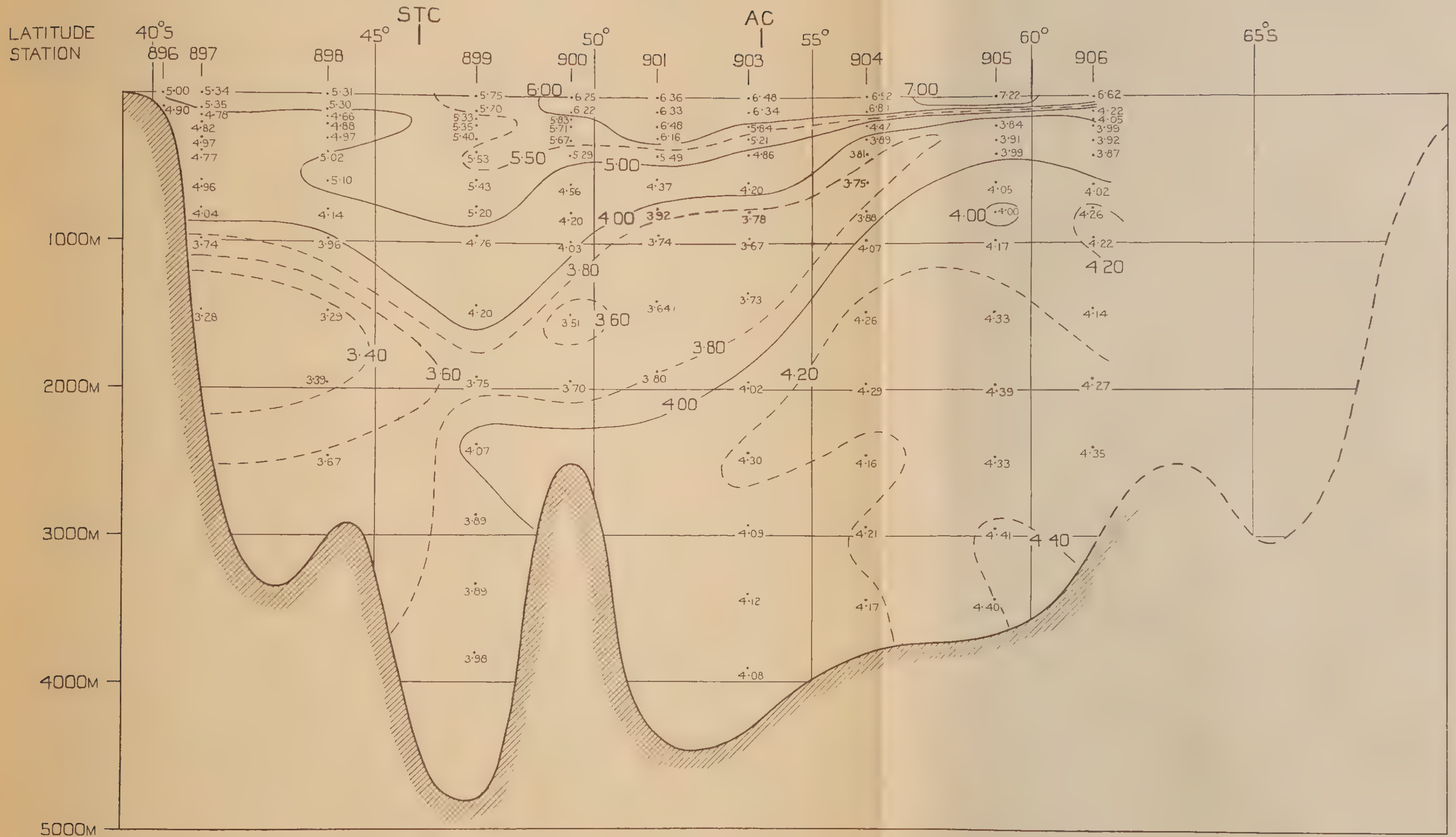
The distribution of oxygen content along section 11 from the ice-edge in 63° 41′ S, 130° 07′ E, south of Australia, to Melbourne, Victoria. May–June 1932.



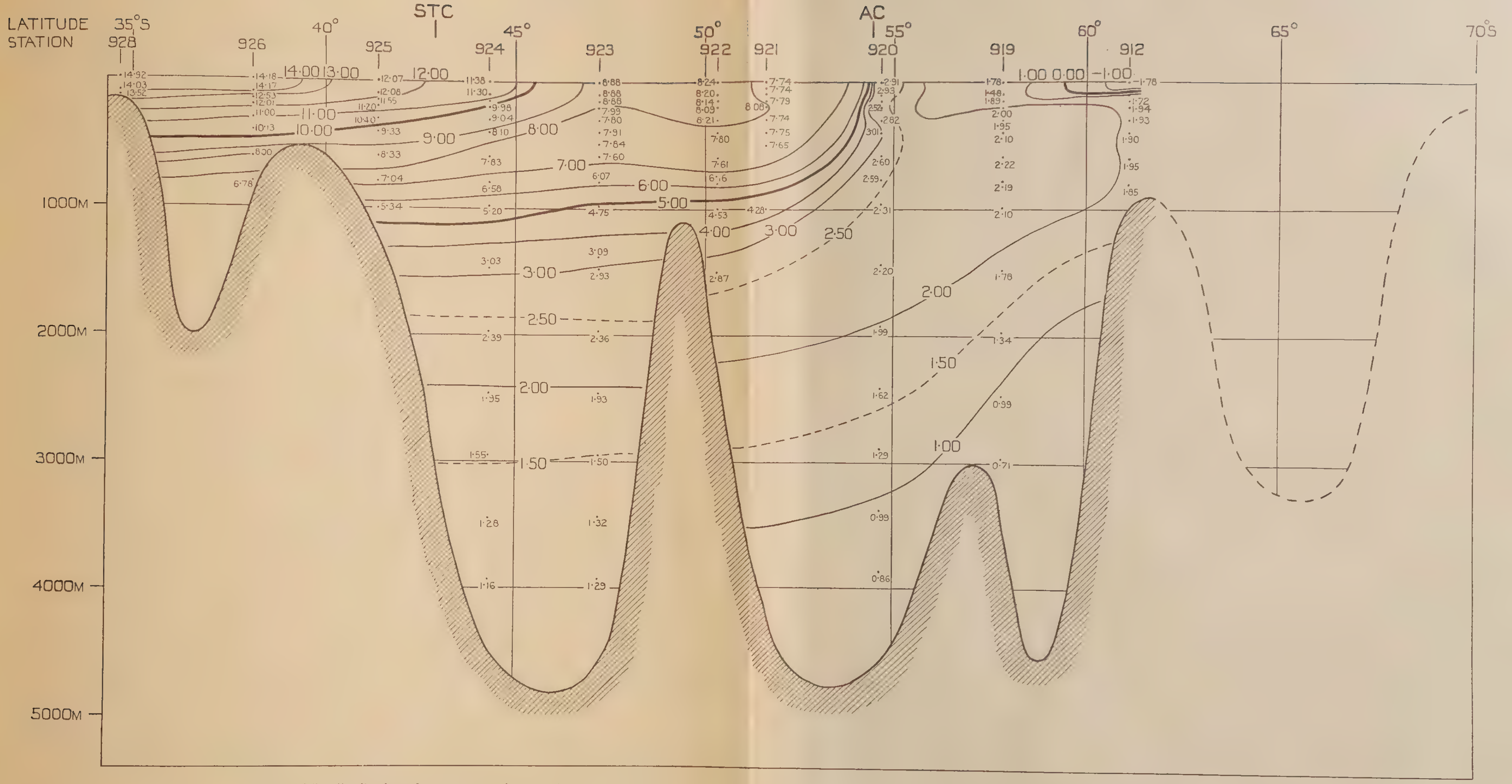
The distribution of temperature along section 12 from Melbourne to the ice-edge in 61° 25′ S, 154° 26′ E, south of the Tasman Sea. June 1932.



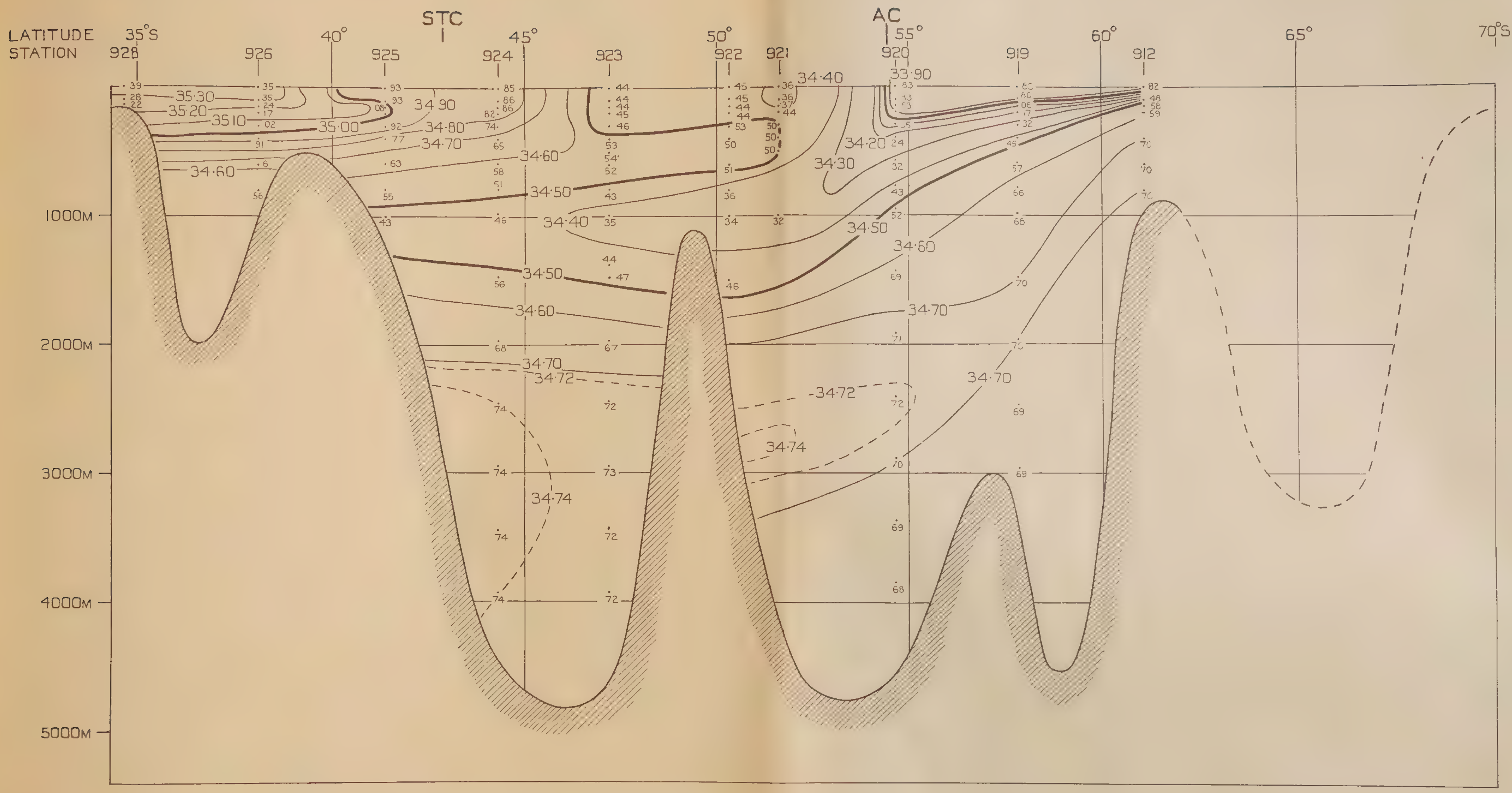
The distribution of salinity along section 12 from Melbourne to the ice-edge in 61° 25′ S, 154° 26′ E, south of the Tasman Sea. June 1932.



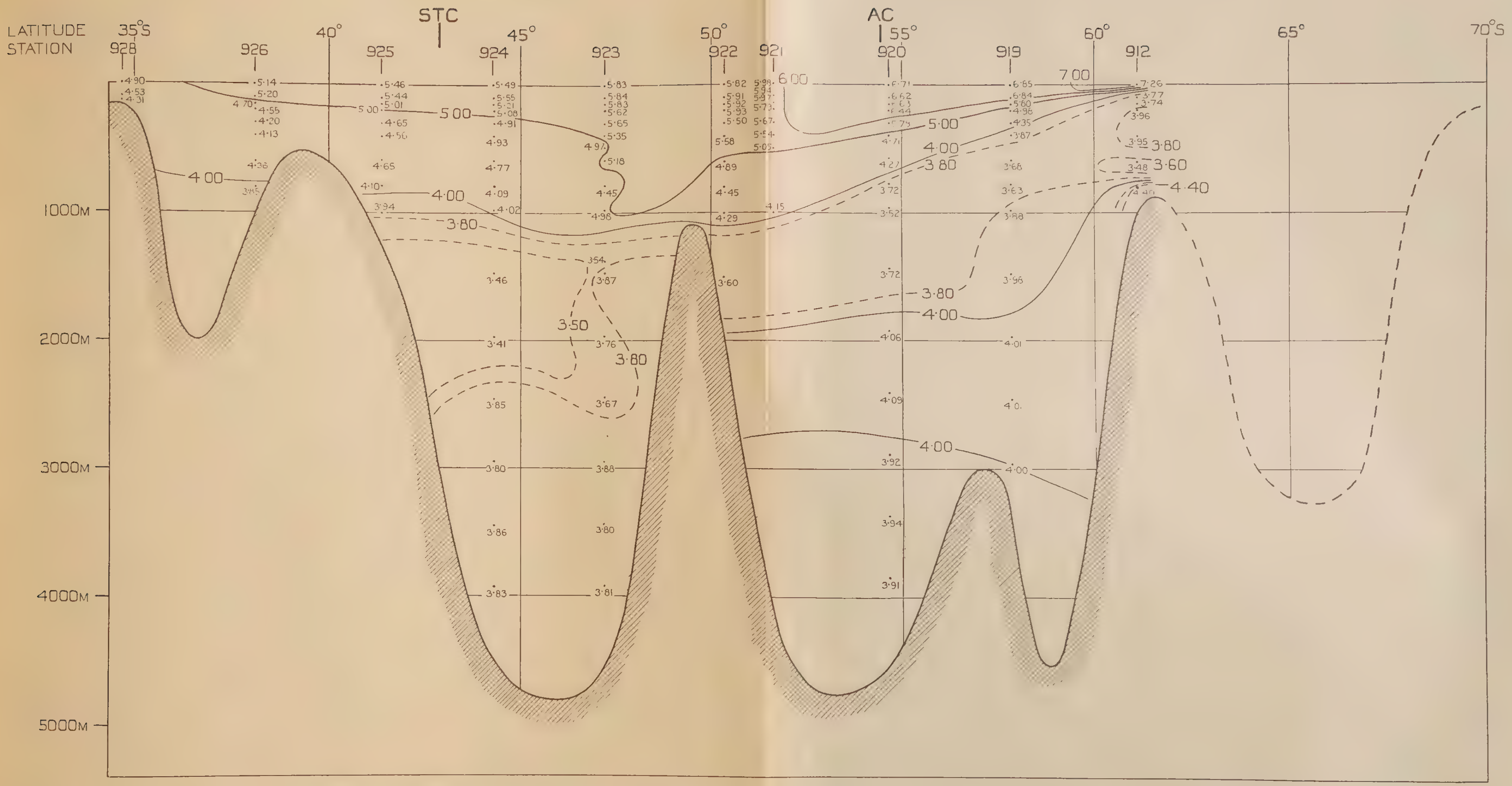
The distribution of oxygen content along section 12 from Melbourne to the ice-edge in 61° 25′ S, 154° 26′ E, south of the Tasman Sea. June 1932.



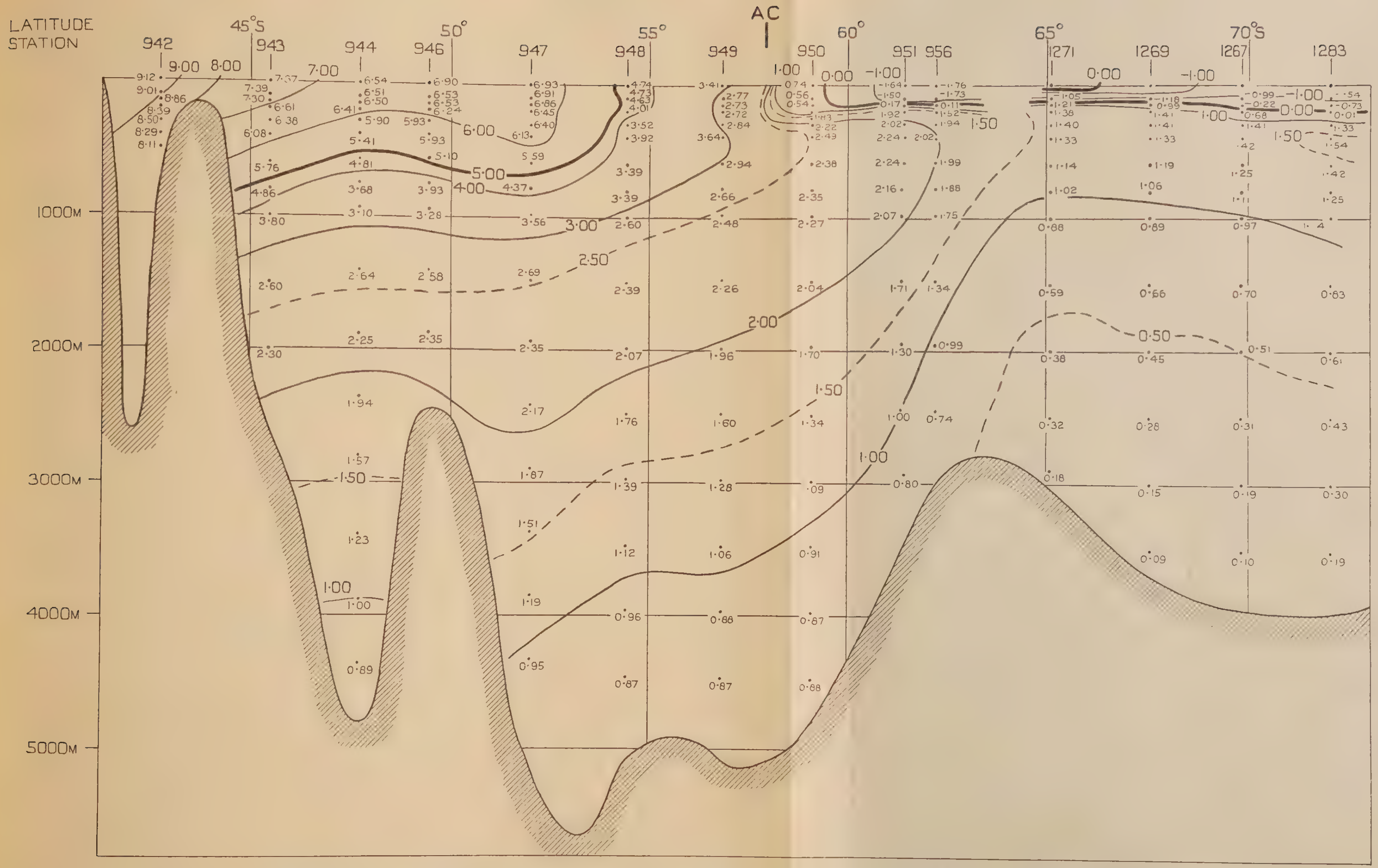
The distribution of temperature along section 13 from the ice-edge in 61° 05′ S, 158° 26′ E, south of the Tasman Sea, to North Cape, New Zealand. June–July 1932.



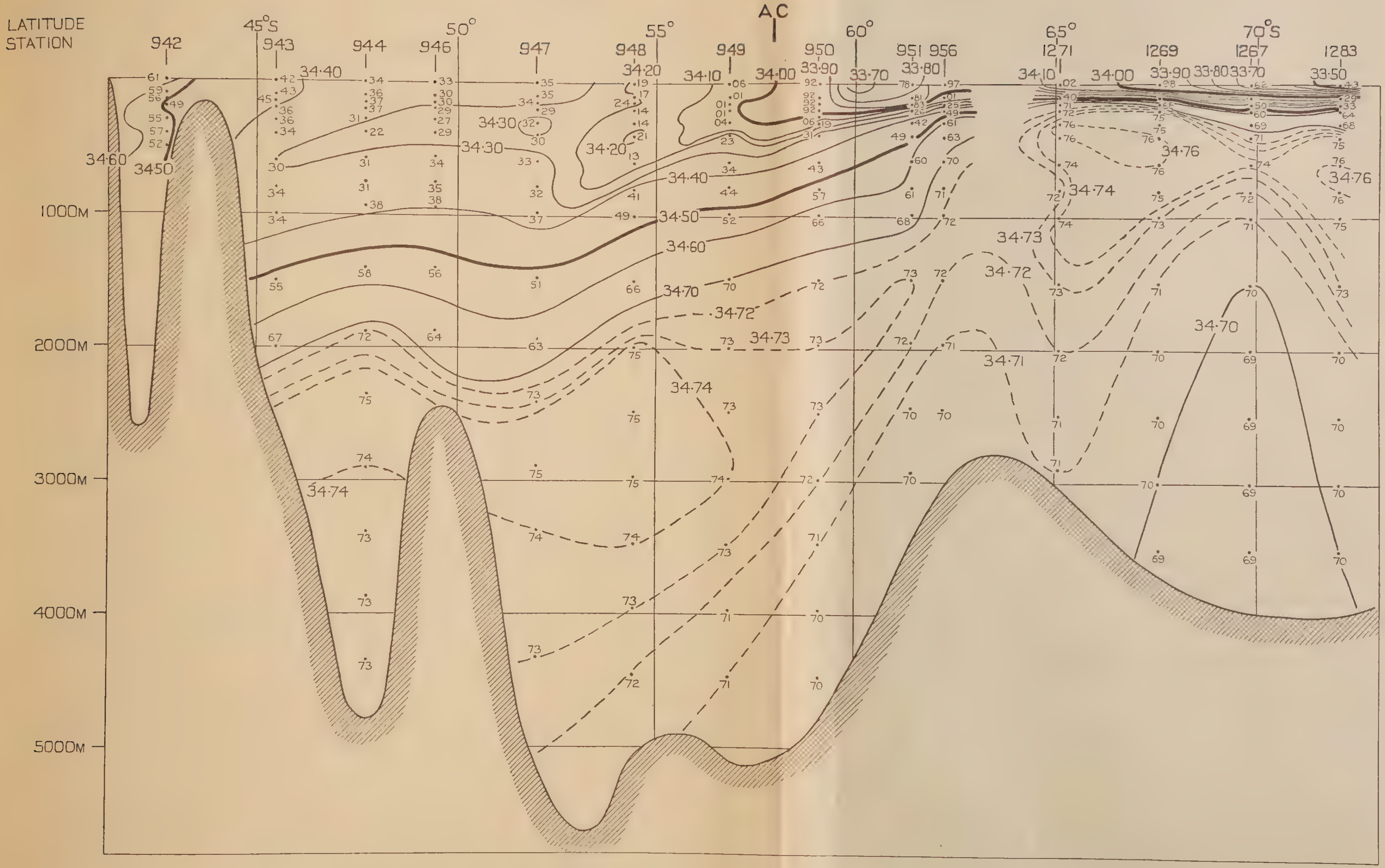
The distribution of salinity along section 13 from the ice-edge in 61° 05′ S, 158° 26′ E, south of the Tasman Sea, to North Cape, New Zealand. June–July 1932.



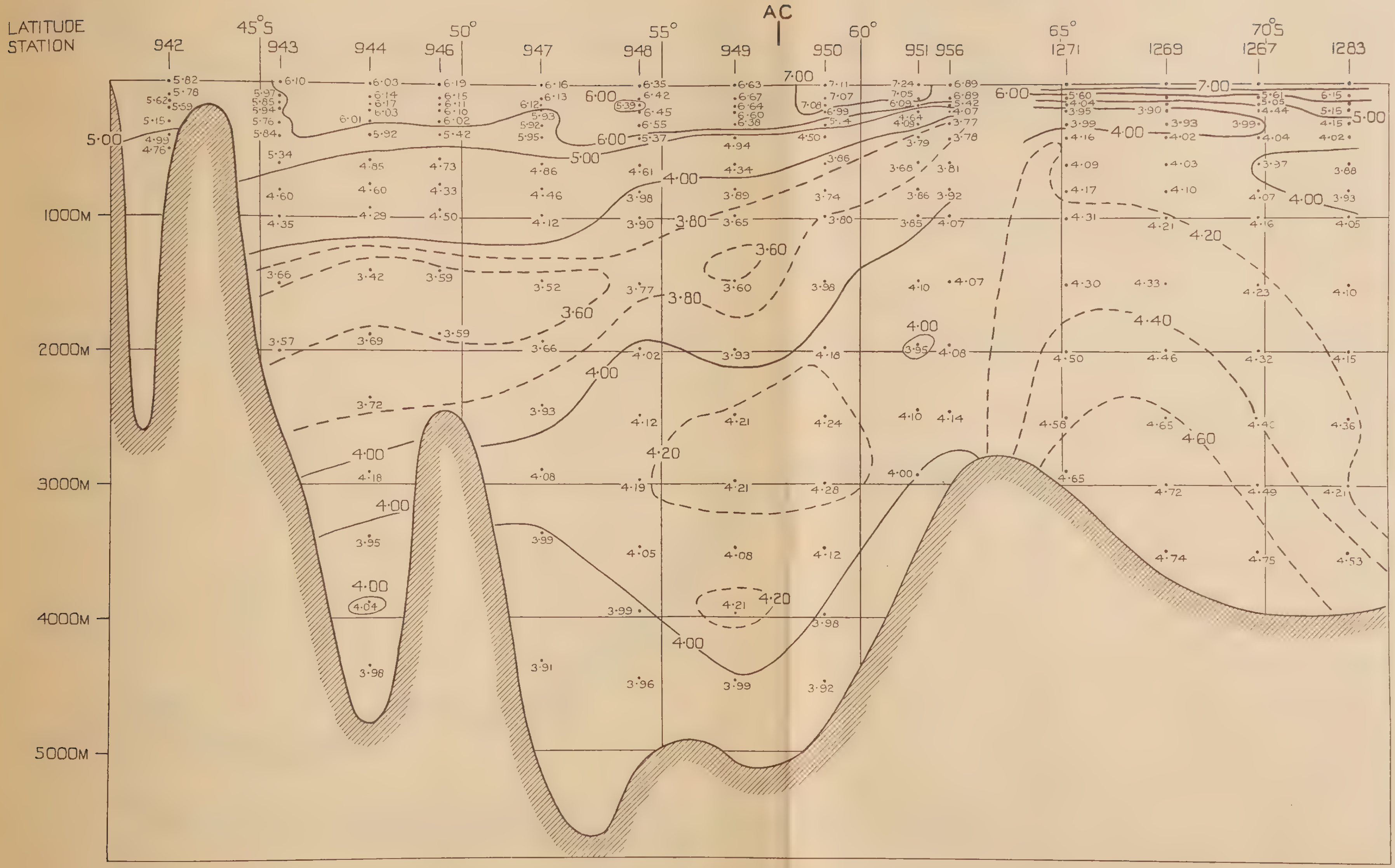
The distribution of oxygen content along section 13 from the ice-edge in 61° 05′ S, 158° 26′ E, south of the Tasman Sea, to North Cape, New Zealand. June–July 1932.



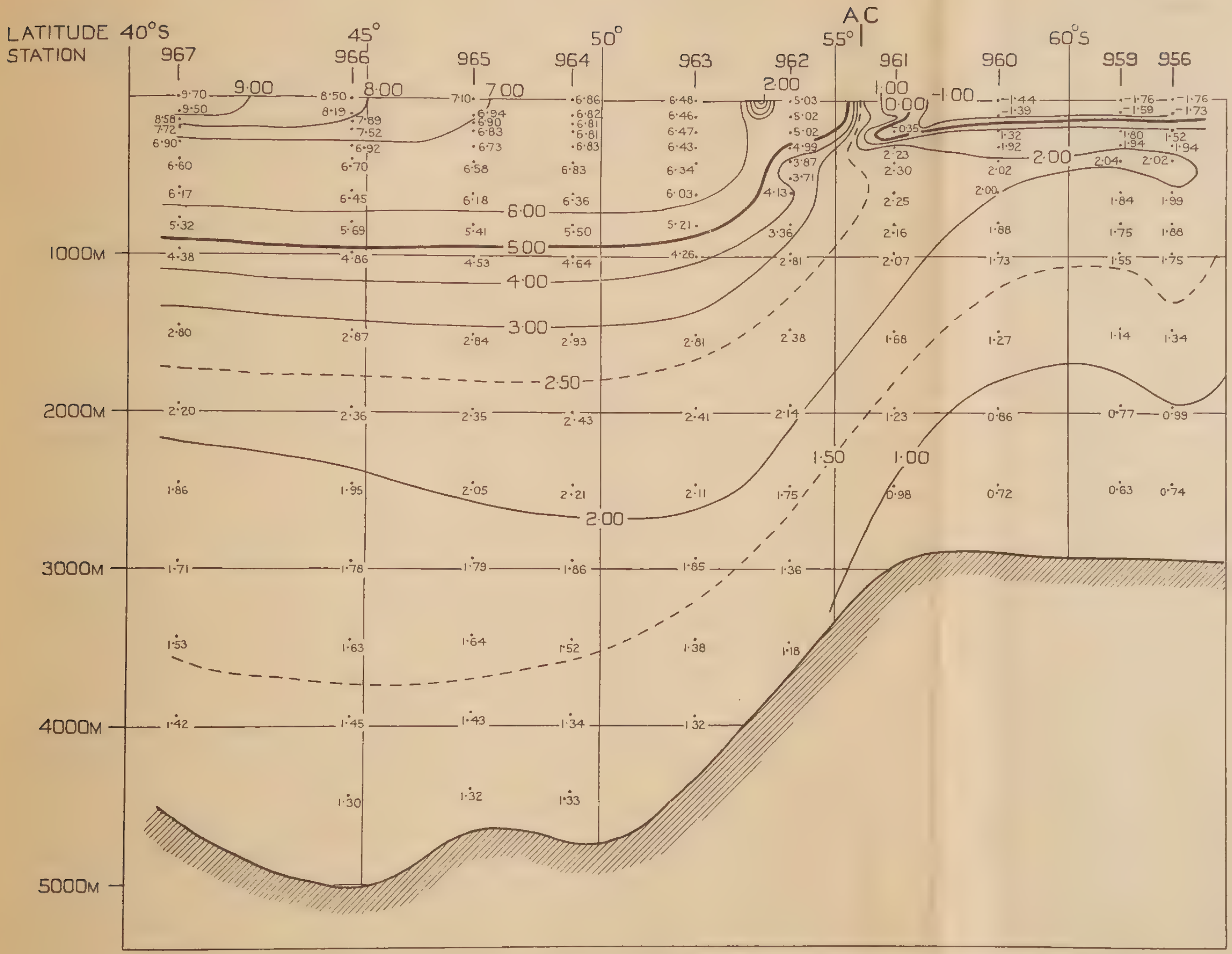
The distribution of temperature along section 14, from Wellington, New Zealand, to 72° 01′ S, 171° 26′ W in the Ross Sea. September 1932, and February 1934.



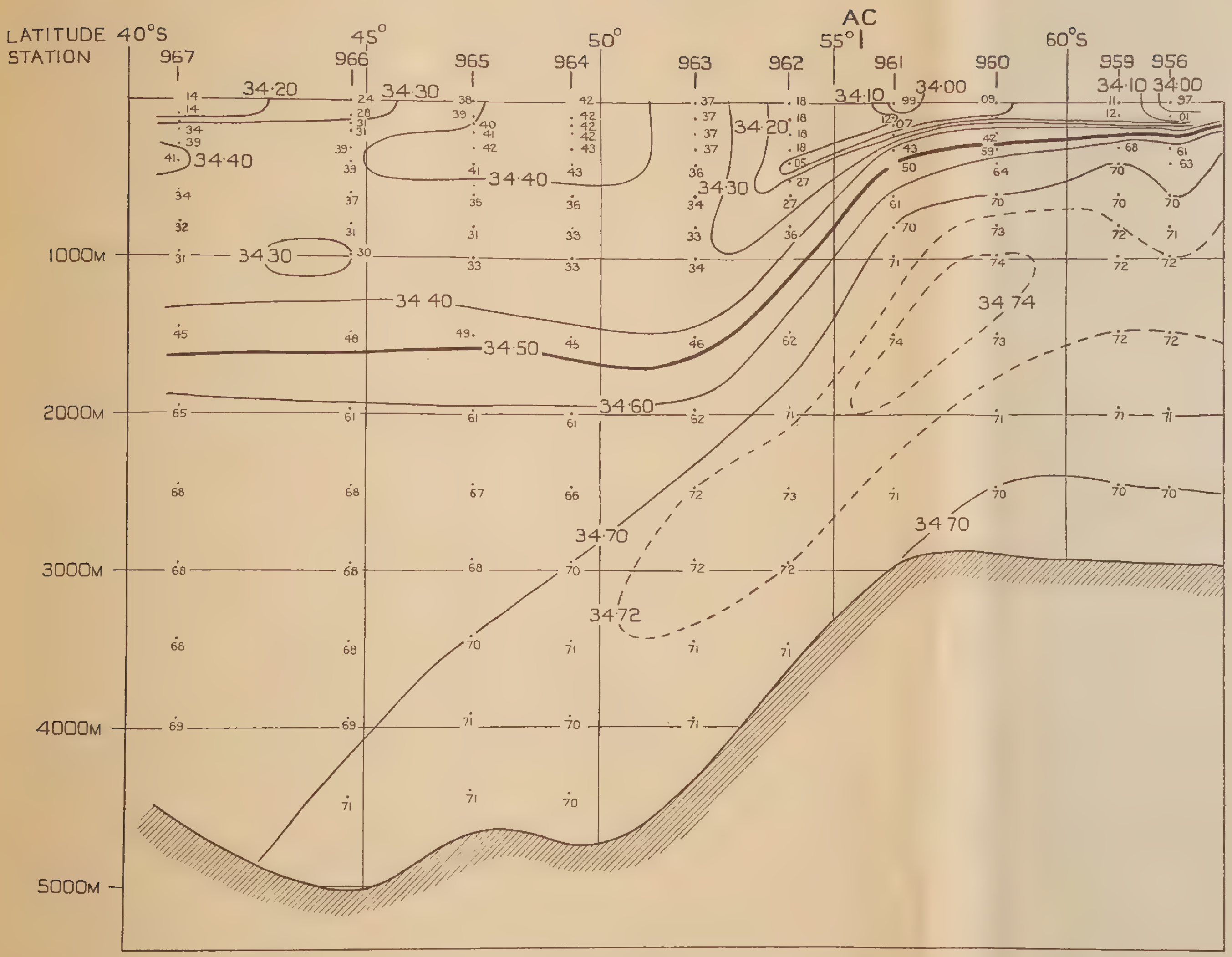
The distribution of salinity along section 14 from Wellington, New Zealand, to 72° 01′ S, 171° 26′ W in the Ross Sea. September 1932, and February 1934.



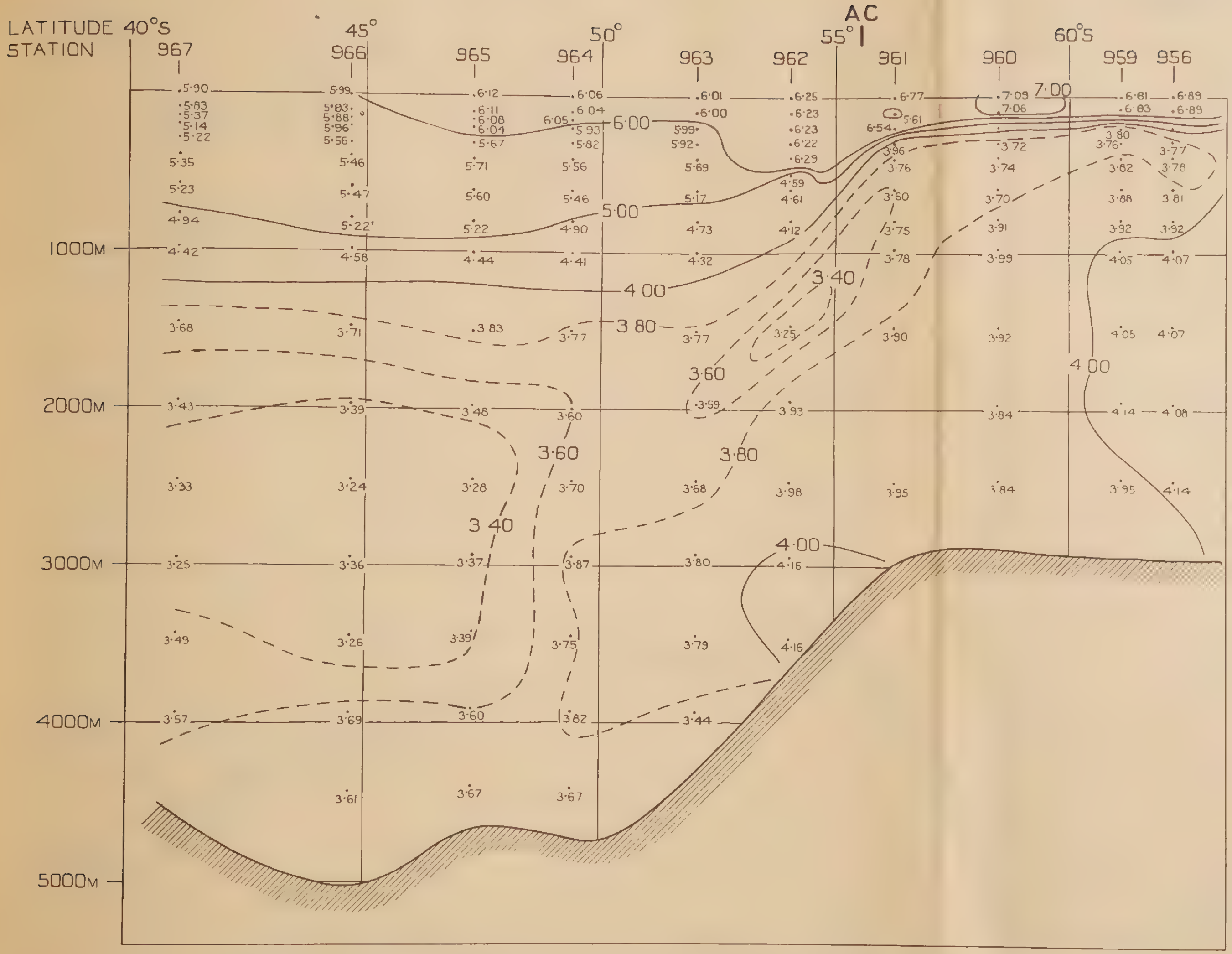
The distribution of oxygen content along section 14 from Wellington, New Zealand, to 72° 01′ S, 171° 26′ W in the Ross Sea. September 1932, and February 1934.



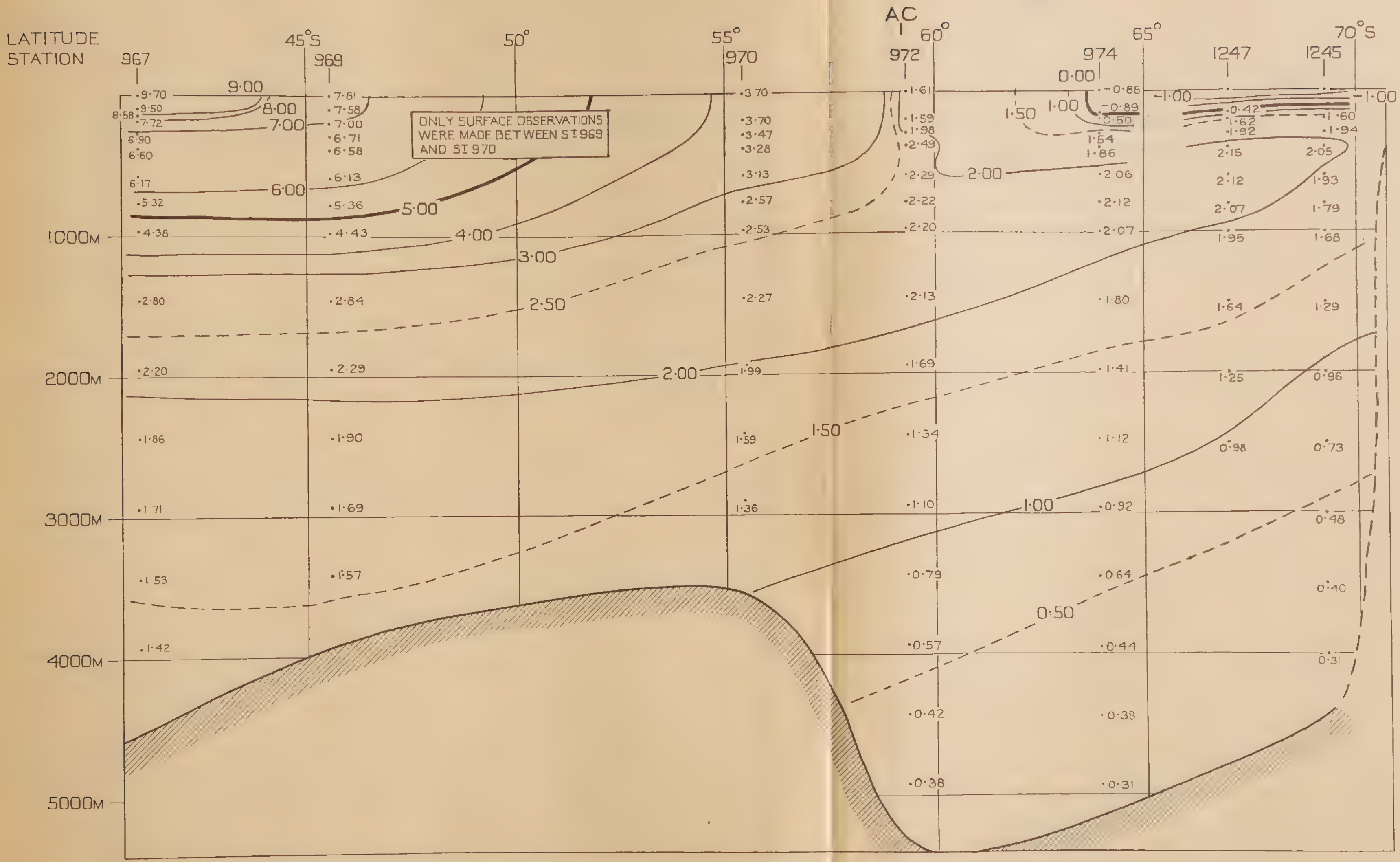
The distribution of temperature along section 15 from the ice-edge in 61° 07′ S, 153° 57′ W, north of the Ross Sea, to 41° 03′ S, 126° 04′ W in the central part of the Pacific Ocean. September 1932.



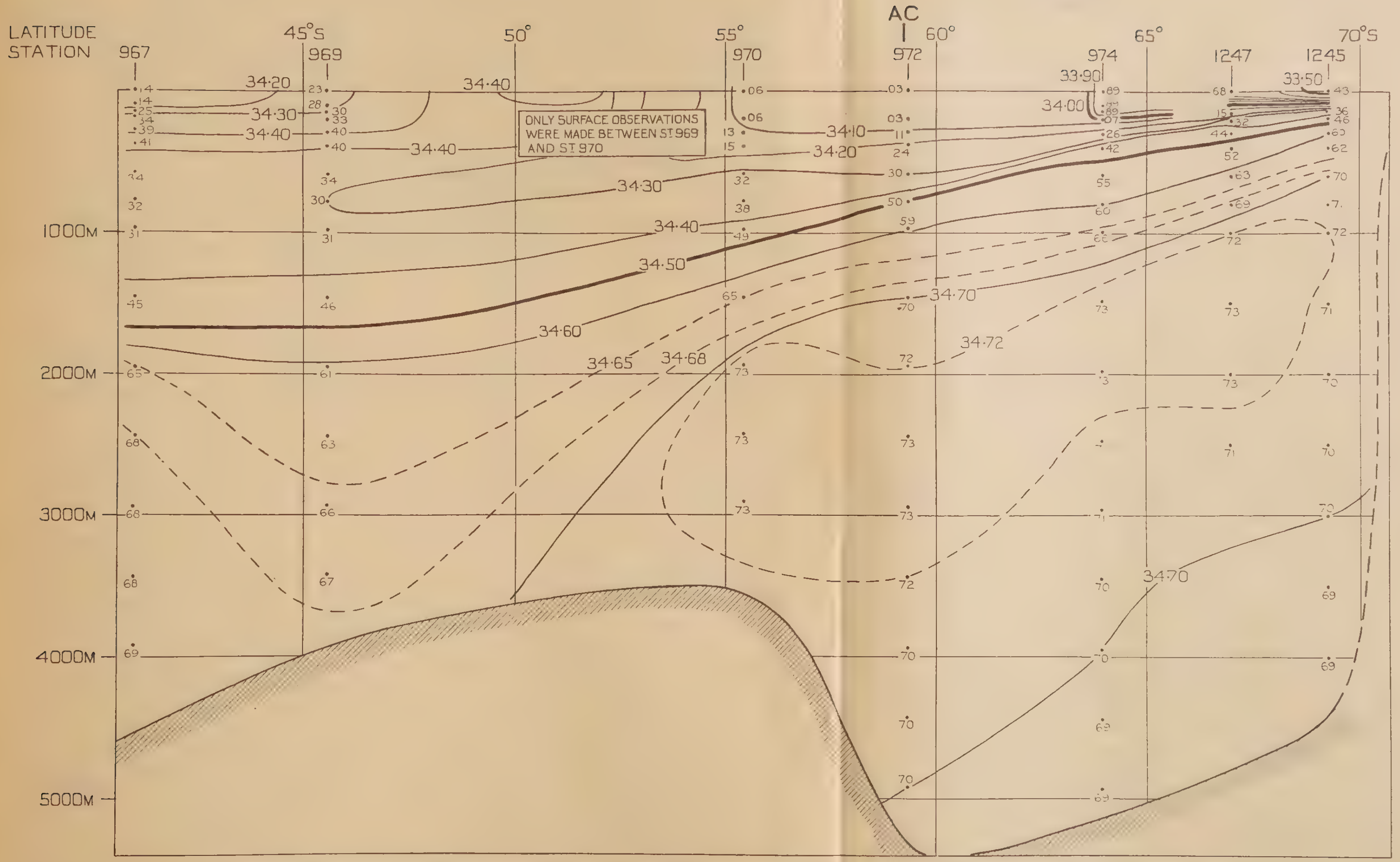
The distribution of salinity along section 15 from the ice-edge in 61° 07′ S, 153° 57′ W, north of the Ross Sea, to 41° 03′ S, 126° 04′ W, in the central part of the Pacific Ocean. September 1932.



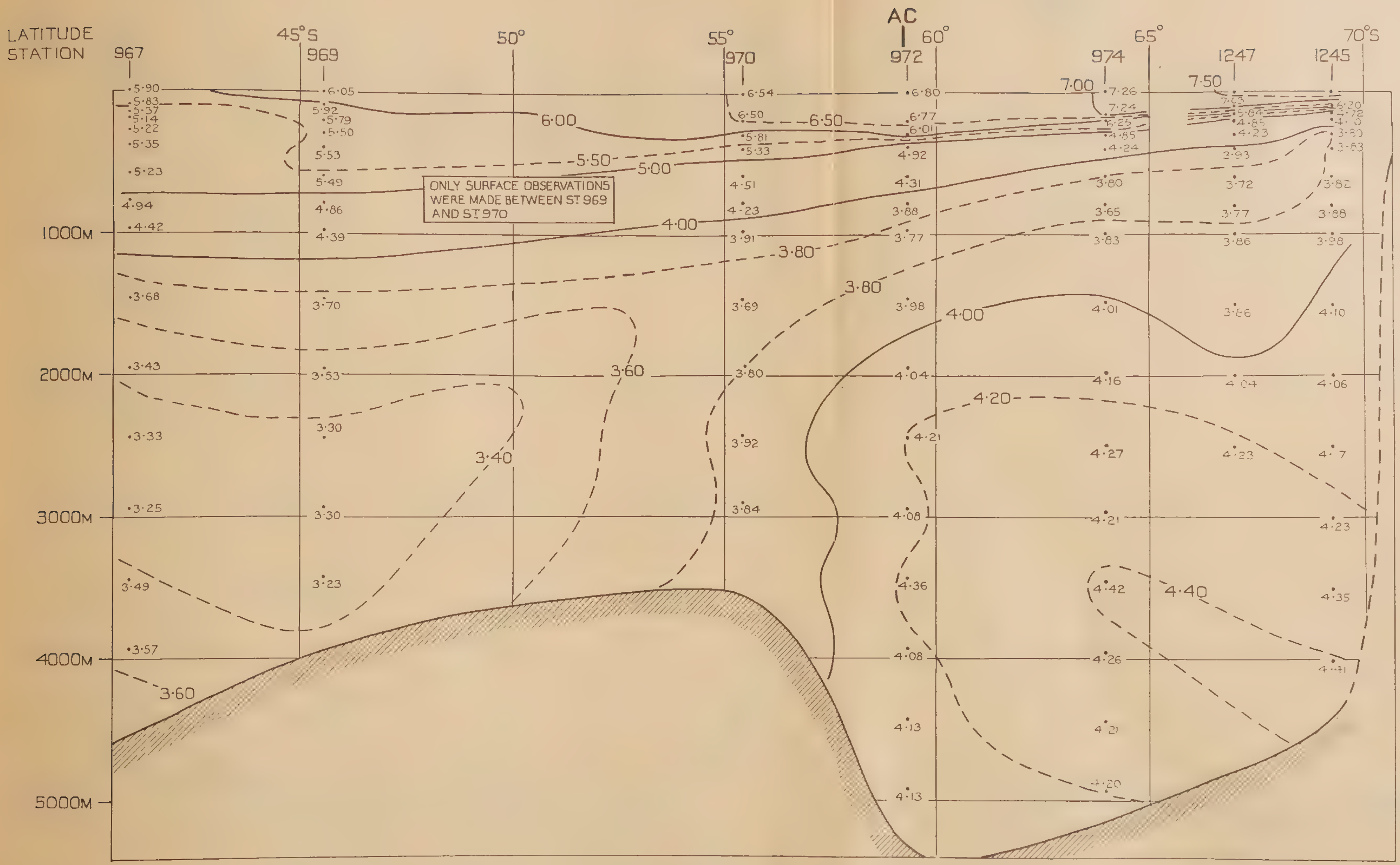
The distribution of oxygen content along section 15 from the ice-edge in 61° 07′ S, 153° 57′ W, north of the Ross Sea, to 41° 03′ S, 126° 04′ W in the central part of the Pacific Ocean. September 1932.



The distribution of temperature along section 16, from the end of section 15 in 41° 03′ S, 126° 04′ W to a point 100–150 miles from the Antarctic shelf in 98° 10′ W. September 1932, and January 1934.

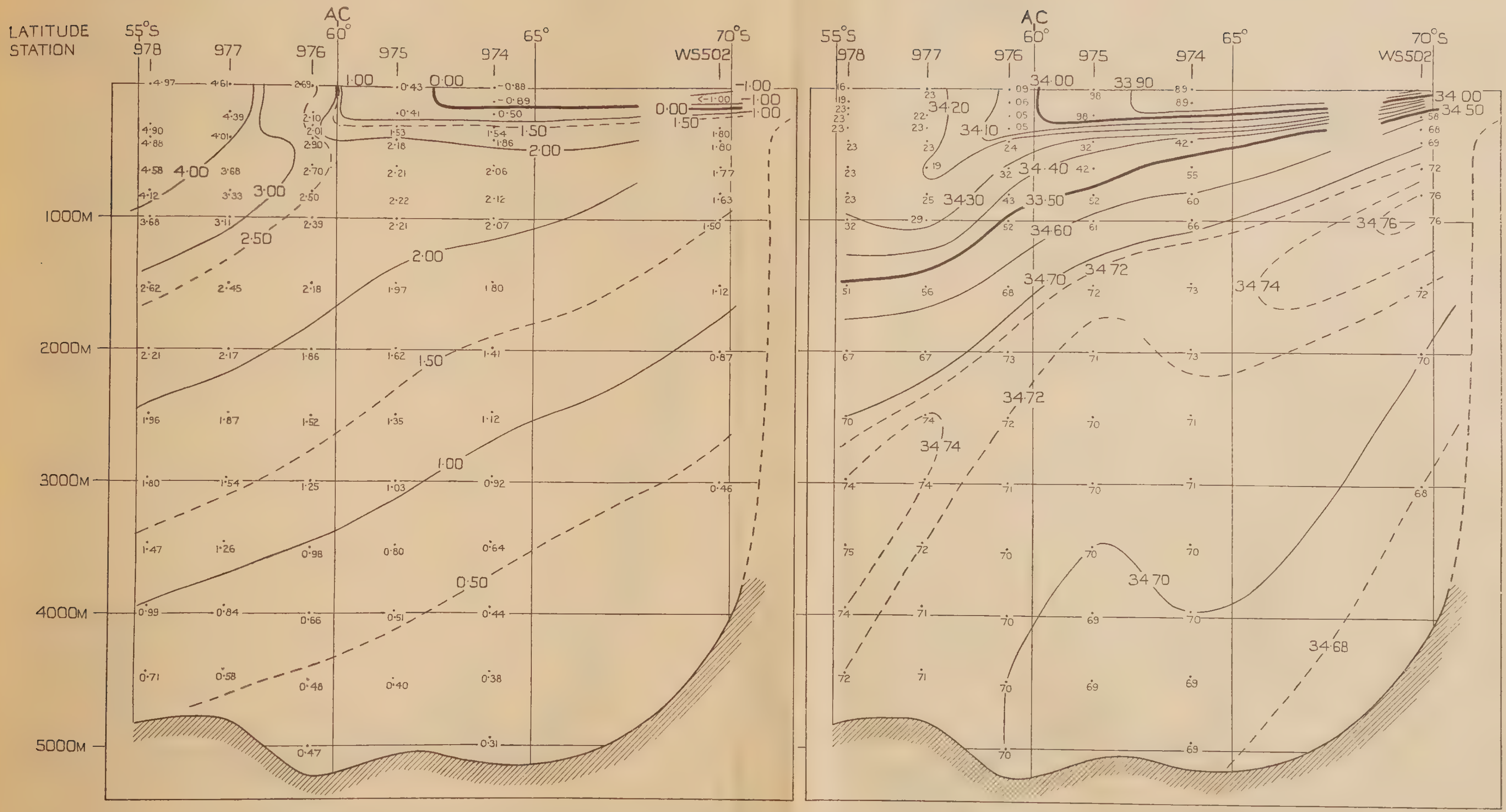


The distribution of salinity along section 16, from the end of section 15 in 41° 03′ S, 126° 04′ W to a point 100–150 miles from the Antarctic shelf in 98° 10′ W. September 1932, and January 1934.

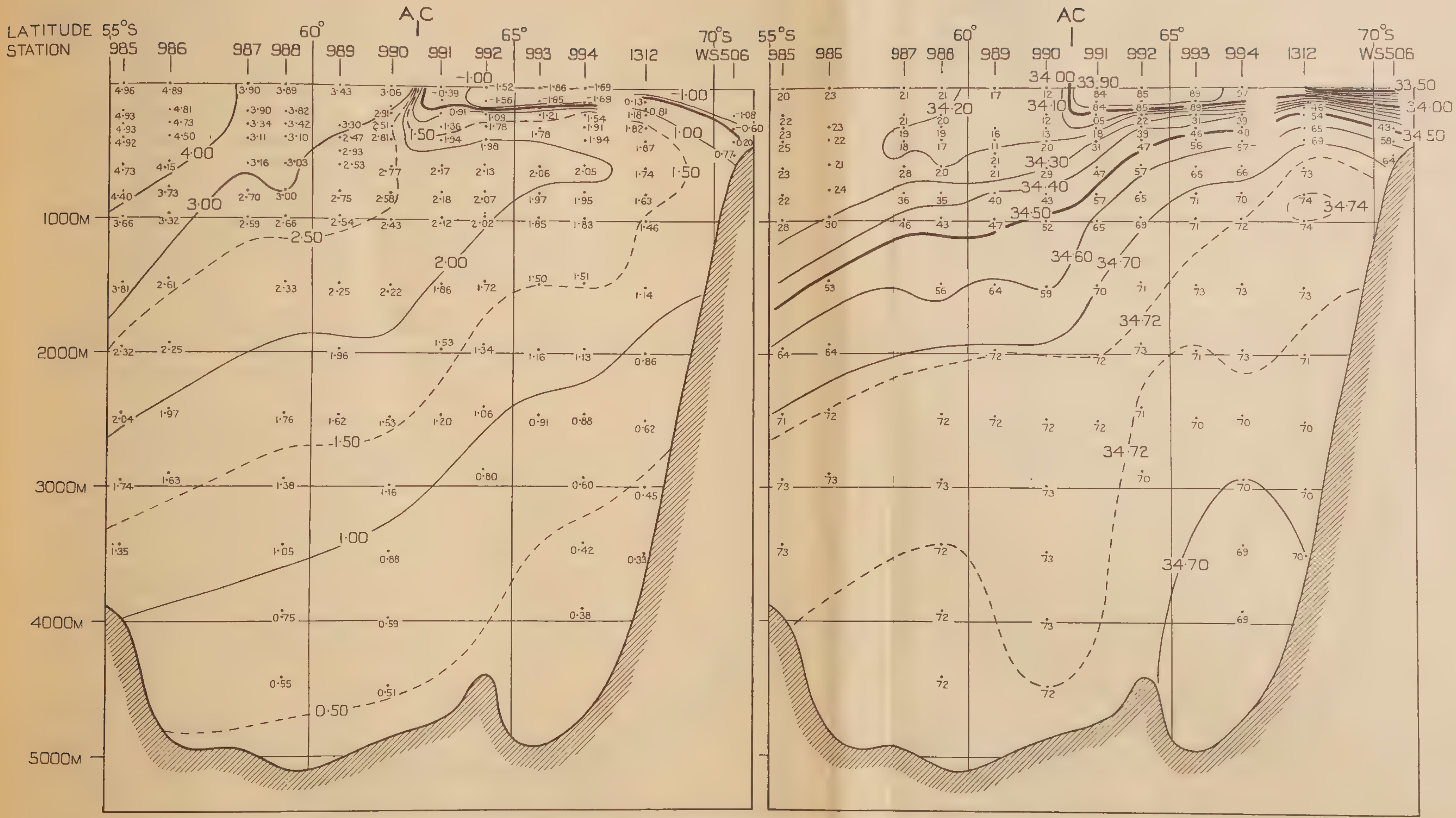


ONLY SURFACE OBSERVATIONS WERE MADE BETWEEN ST. 969 AND ST. 970

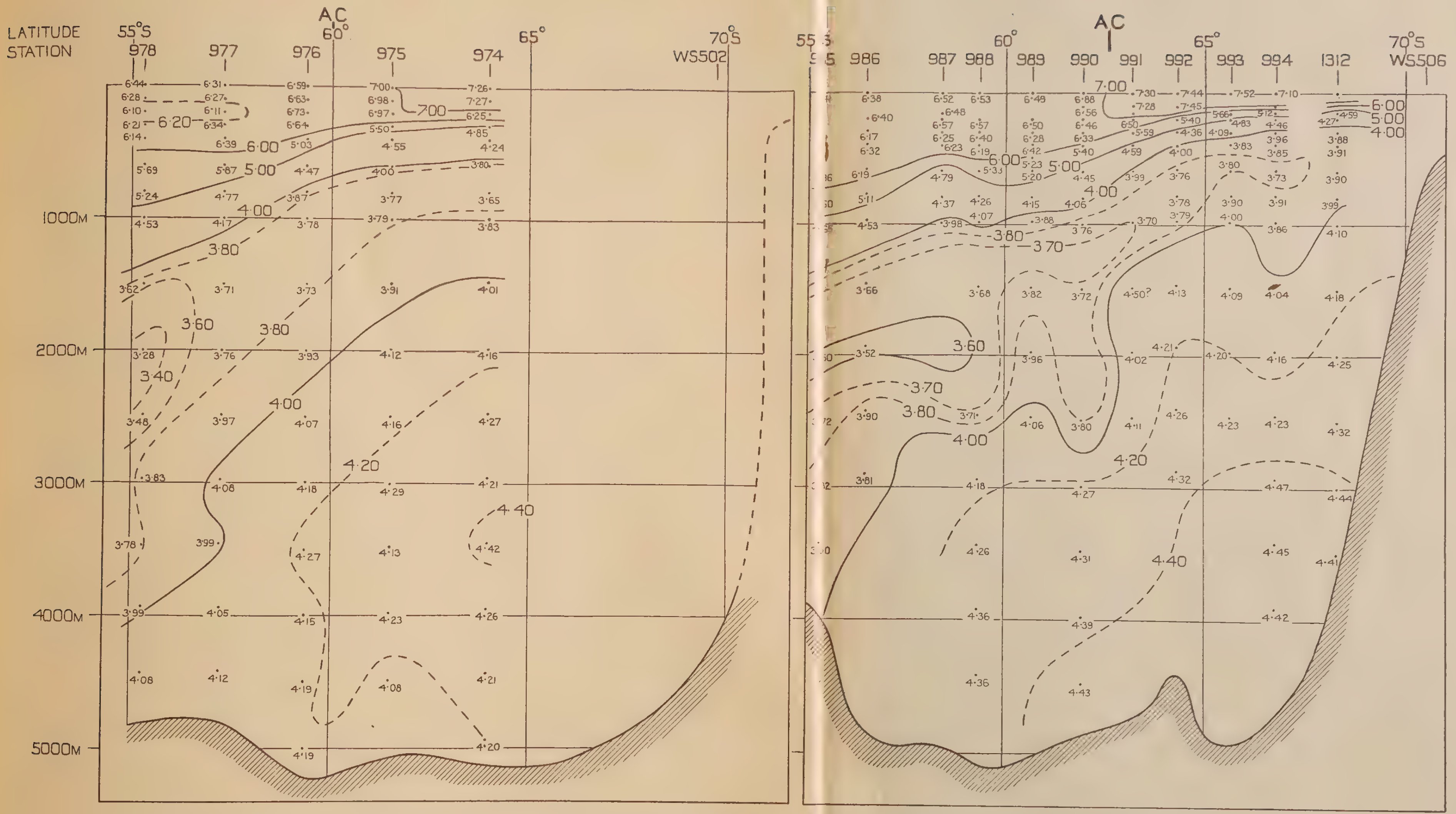
The distribution of oxygen content along section 16, from the end of section 15 in 41° 03′ S, 126° 04′ W. to a point 100–150 miles from the Antarctic shelf in 98° 10′ W. September 1932, and January 1934.



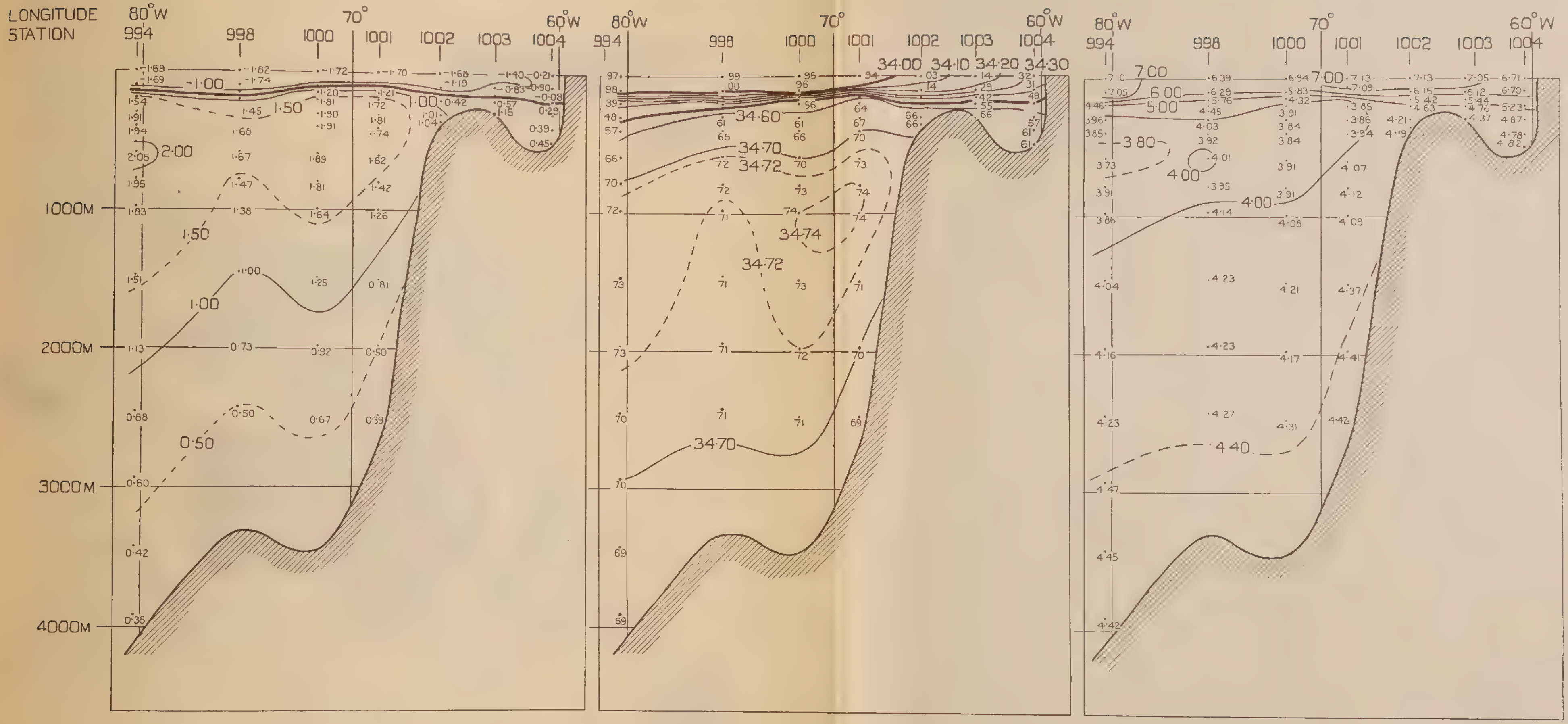
The distribution of temperature and salinity along section 17, from 69° 43′ S, 99° 38′ W within 100 miles of the Antarctic shelf, to the western end of the Magellan Strait. September–October 1932, and January 1930.



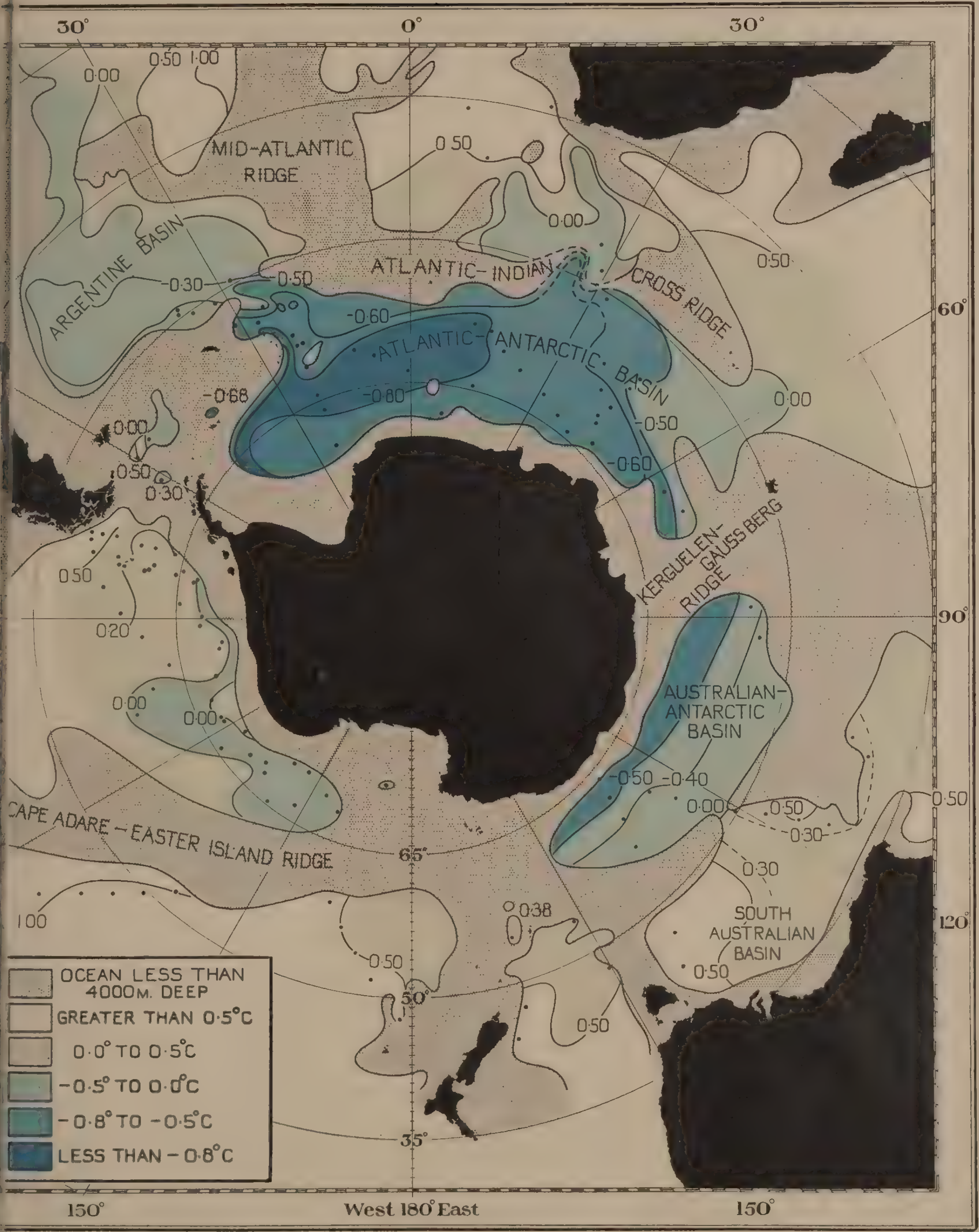
The distribution of temperature and salinity along section 18, a longitudinal section from 55° 20′ S to 70° 31′ S in 80° W. October 1932, March 1934, and February 1930.



The distribution of oxygen content along section 17, from 69° 43′ S, 99° 38′ W within 100 miles of the Antarctic shelf, to the western end of the Magellan Strait; September–October 1932 and January 1930, and along section 18, a longitudinal section from 55° 20′ S to 70° 31′ S in 80° W. October 1932, March 1934, and February 1930.



The distribution of temperature, salinity, and oxygen content along section 19, from 66° 46′ S, 80° 20′ W in the south-western part of the Drake Passage to Deception Island. October 1932.


30°
0°
30°
0·00
0·50
1·00
MID-ATLANTIC RIDGE
0 50
0·00
0·50
ARGENTINE BASIN
-0·30
-0·50
ATLANTIC-INDIAN
CROSS RIDGE
60°
-0·60
ATLANTIC-ANTARCTIC BASIN
-0·68
-0·80
0·00
-0·50
-0·60
0·50
0·30
KERGUELEN-GAUSSBERG RIDGE
0·50
90°
0·20
AUSTRALIAN-ANTARCTIC BASIN
0·00
0·00
-0·50
-0·40
0·00
0·50
0·30
0·50
CAPE ADARE – EASTER ISLAND RIDGE
65°
0·30
1·00
0·38
SOUTH AUSTRALIAN BASIN
120°
0·50
0·50
50°
0·50
35°
OCEAN LESS THAN 4000M. DEEP
GREATER THAN 0·5°C
0·0° TO 0·5°C
-0·5° TO 0·0°C
-0·8° TO -0·5°C
LESS THAN -0·8°C
150°
West 180° East
150°

he potential temperature (see p. 82) of the bottom water in the Southern Ocean at depths greater than 4000 m.

[*Discovery Reports. Vol. XV, pp.* 125–152, *March,* 1937]

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

# NOTE ON THE DYNAMICS OF THE SOUTHERN OCEAN

By
G. E. R. DEACON, B.Sc.

# CONTENTS

Introduction . . . . . . . . . . . . . . . . . . . . *page* 127

Bjerknes' theorem of oceanic circulation . . . . . . . . . . . 128

The application of Bjerknes' theorem to oceanographical problems . . . 130

The dynamical topography of the 0 and 600 decibar surfaces in the Southern Ocean . . . . . . . . . . . . . . . . . . . . 132

The problem of the meridional water circulation in the Southern Ocean . 140

References . . . . . . . . . . . . . . . . . . . . 141

# NOTE ON THE DYNAMICS OF THE SOUTHERN OCEAN

By G. E. R. Deacon, B.Sc.

(Text-figs. 1–4)

## INTRODUCTION

One of the most important tasks undertaken in the course of the extensive researches which the Discovery Committee has been conducting into the hydrological and biological conditions in the Southern Ocean is to find how the plankton distribution in the sea depends on the water movements, and although much knowledge has already been gained, many aspects of the problem—chiefly those concerned with the speeds of the water and plankton movements—cannot be settled until a more trustworthy representation of the water movements has been obtained.

After a long examination of the hydrological data, mostly obtained from the Falkland Sector, it seemed almost certain that the method generally employed—the application of Bjerknes' theorem of oceanic circulation, in its specialized form, to the density and pressure distribution—did not give such reliable results in the Southern Ocean as it does in other parts of the world.

Where the theorem can be relied on implicitly the movement in the neighbourhood of each isobaric surface conforms to the dynamical topography of the surface and follows the isobaths, but the accumulated data from the Falkland Sector pointed to the existence of relatively strong movements across the isobaths; the warm deep current, for example, seems to have a stronger southward trend. Although it must be admitted that the counter evidence was not unquestionable, there was a strong indication that the topographical charts did not give an accurate representation of the current system.

With the problem at this stage the results obtained during the circumpolar cruise made by the R.R.S. 'Discovery II' in 1932–3 presented a unique opportunity for testing the usefulness of the charts on a wider scale, and for the first time charts could be drawn to show the relative topographies of the isobaric surfaces round the whole of the Southern Ocean. Charts showing the topographies of the 0 and 600 decibar surfaces relative to the 3000 surface are given in this report, and a comparison of the conclusions that can be drawn from them with others drawn from a more general treatment of the temperature and salinity data (Deacon, 1937) also indicates that the specialized form of Bjerknes' theorem does not give a true picture of the currents.

In the hope that the problem would interest more skilful workers the complete data—anomalies of specific volume and dynamic depth—for 113 stations in the Southern Ocean are given in Tables at the end of this report. In order to make the report more complete it was thought useful to begin it with a brief indication of the method by which Bjerknes' theorem has been developed; the method is taken chiefly from a paper published by Sandström and Helland-Hansen in 1903.

## BJERKNES' THEOREM OF OCEANIC CIRCULATION

In order to find the relation between the pressure and density distribution in the sea and the water movements Bjerknes has studied the dynamics of a closed curve composed of water particles in the sea. In general the velocity of each particle will have a component along the curve and Bjerknes has called the sum of these components the *circulation* of the curve. If the tangential velocity along an element $ds$ of the curve is given as $v_t$, then the circulation $C_a$ is expressed by the integral formula

$$C_a = \int v_t . ds,$$

or if the velocity is given relative to the rotating earth as $u_t$ the relative circulation $C_r$ is given by the analogous formula

$$C_r = \int u_t . ds.$$

Between the absolute and relative circulations Bjerknes has deduced the simple relation

$$C_a = C_r + 2\omega S \qquad \text{......(1)},$$

where $\omega$ is the angular velocity of the earth, and $S$ is the area of the projection of the closed curve on the plane of the Equator.

In the deduction of his general theorem Bjerknes has calculated the change of the relative circulation with time $\frac{dC_r}{dt}$ on the assumption that the water movements are affected only by gravity, the distribution of pressure and density, the earth's rotation, and friction. If the component of acceleration along an element of the curve is $\dot{u}_t$, then $\frac{dC_r}{dt}$, usually known as the acceleration of the circulation, is given by the equation

$$\frac{dC_r}{dt} = \int \dot{u}_t . ds,$$

or if $\dot{u}_t$ is expressed as the sum of a series of vectors which represent the tangential components of the accelerations due to each of the factors mentioned above on the water particles

$$\frac{dC_r}{dt} = \int g_t . ds + \int p_t . ds + \int d_t . ds + \int f_t . ds \qquad \text{......(2)}.$$

The first vector represents the tangential component of the acceleration due to gravity: $g_t . ds$ is therefore the work which must be done to move a unit mass along the element $ds$ in opposition to the force of gravity, and $\int g_t . ds$ is that which would be done if a unit mass were moved round the whole of the closed curve. Since, however, such a cycle would bring the unit mass back to the point from which it started the total work done, $\int g_t . ds$, is zero.

The second vector in equation (2), $p_t$, is the tangential acceleration due to the pressure gradient. It will be directly proportional to the gradient $\frac{dp}{ds}$ along the curve and inversely proportional to the density $\rho$, so that

$$p_t = -\frac{1}{\rho}\cdot\frac{dp}{ds},$$

the negative sign showing that the acceleration is directed towards the low pressure. If the expression is given in terms of the specific volume of the water $v$ instead of density

$$p_t = -v\frac{dp}{ds}$$

and

$$\int p_t\,.\,ds = -\int v\,.\,dp.$$

The third integral in equation (2), $\int d_t\,.\,ds$, representing the influence of the earth's rotation, enters the expression for the change of relative circulation only, and since the absolute and relative circulations are equally influenced by the other factors, gravity, pressure and density differences, and friction, it follows that

$$\frac{dC_a}{dt} = \frac{dC_r}{dt} - \int d_t\,.\,ds$$

and afterwards, by comparison with the differentiated form of equation (1)

$$\frac{dC_a}{dt} = \frac{dC_r}{dt} + 2\omega\frac{dS}{dt},$$

that

$$\int d_t\,.\,ds = -2\omega\frac{dS}{dt}.$$

The last integral in equation (2), a measure of the effect of friction on the circulation, has so far not been evaluated, the only practicable method being to use equation (2) when all the other terms are known. To shorten the final form of the equation, however, the integral $\int f_t\,.\,ds$ has been written as $-R$, the negative sign showing that the friction has a retarding influence.

Substituting the new values for the four integrals in equation (2) it is found that

$$\frac{dC_r}{dt} = -\int v\,.\,dp - 2\omega\frac{dS}{dt} - R.$$

The first term on the right-hand side of the equation is of particular importance since it is a measure of the primary cause of the movements in the sea, the pressure and density differences. The earth's rotation and friction represented by the last two terms can only deform an existing current.

For a closed curve in the sea $\int v\,.\,dp$ is equal to the number of isobar-isostere tubes, tubes formed by the intersection of the isobaric and isosteric surfaces, that are enclosed by the curve. Each of these tubes is known as a solenoid, and writing the number of solenoids enclosed by the curve as $A$ Bjerknes expresses his general theorem of circulation

$$\frac{dC_r}{dt} = A - 2\omega\frac{dS}{dt} - R \qquad \ldots\ldots(3).$$

So far it has been found impracticable to apply this general expression to actual oceanographical problems, and the difficulty of evaluating the terms $\frac{dC_r}{dt}$ and $R$ has limited the use of the theorem to current systems in which both of these magnitudes are small enough to be neglected. In such circumstances the general theorem becomes a specialized theorem which implies that the solenoid field is balanced by the influence of the earth's rotation, so that

$$2\omega \frac{dS}{dt} = A \qquad \text{......(4).}$$

Generally the conditions under which $\frac{dC_r}{dt}$ and $R$ can be neglected will not be found in the sea, but the close agreement that has been found between the actual and theoretical currents in many parts of the world—in the Gulf Stream (Wüst, 1924) and in the region south of Newfoundland (Smith, 1925) for example—shows that the actual conditions must often approximate to such conditions.

## THE APPLICATION OF BJERKNES' THEOREM TO OCEANOGRAPHICAL PROBLEMS

The most convenient form of closed curve that can be studied dynamically is one which is built up of two verticals $a$ and $b$ with two isobaric lines along which the pressures are $p_0$ and $p_1$ joining their upper and lower extremities. Since the pressure gradients along the isobaric lines are zero the number of solenoids enclosed by the curve is

$$-\int_{p_0}^{p_1} v_a \, . dp + \int_{p_0}^{p_1} v_b \, . dp,$$

or, if $\bar{v}_a$ and $\bar{v}_b$ are the average specific volumes of the water in the two vertical columns,

$$\bar{v}_a (p_0 - p_1) - \bar{v}_b (p_0 - p_1) \qquad \text{......(5).}$$

If the sea surface is used as the upper isobaric surface and the pressure of the atmosphere is disregarded, the pressure $p_1$ at a depth $h$, if the water has a mean specific volume $\bar{v}$, is $\frac{hg}{\bar{v}}$, the weight of a water column of unit cross section and depth $h$. Substituting analogous values for the pressure difference $p_0 - p_1$ in equation (5) the number of solenoids enclosed by the curve, when the upper isobaric surface coincides with the sea surface, is given by the equation

$$A = h_a g - h_b g,$$

where $h_a$ and $h_b$ are the depths of the lower isobaric surface along the two verticals.

The two terms on the right-hand side of the equation represent the work which must be done against gravity in raising unit masses from the lower isobaric surface to the sea surface along the two verticals $a$ and $b$, and such measures of work or change of potential have been called by Bjerknes the *dynamic depths* of the lower isobaric surface along the two verticals. Using this notation the number of solenoids enclosed by the curve formed by the two verticals, the lower isobaric surface, and the sea surface, is equal to the difference of the dynamic depths. In a study of the dynamics of the sea the dynamic depths are therefore magnitudes of the first importance and they are usually tabulated with the results. The unit of dynamic depth in most common use is the *dynamic metre* which corresponds to 10 units of work or change of potential on the metre-ton-second scale. The dynamic metre is approximately 2 per cent greater than the common metre near the Equator and 5 per cent greater near the poles.

The dynamic depths are usually obtained by evaluating the integral $\int v.dp$ as accurately as possible for each vertical series of temperature and salinity observations: the mean specific volume of the water in each interval of depth is multiplied by the difference of pressure in the interval (approximately the same as the difference of depth when decibars and metres are employed as units) and the values of $v.dp$ so obtained are summed downwards from the surface to each of the isobaric surfaces whose dynamic depth is required. Several methods have been devised for shortening the process of integration. Sandström and Helland-Hansen (1903, pp. 14–35), and Sverdrup (1933) worked with anomalies of specific volume referred to a standard sea of uniform temperature 0° C. and salinity 35·00 °/₀₀, so that they had to deal with numbers of not more than three figures instead of with five-figure numbers, and Hesselberg and Sverdrup (1915, pp. 1–17) showed that it was also easier to work with figures for $1 - v$ instead of $v$. Further time and space can also be saved if only the anomalies of dynamic depth are calculated and tabulated; these will generally serve the same purposes as the dynamic depths themselves and they can easily be converted to them if necessary.

The closed curve consisting of two verticals with their upper and lower extremities joined by isobaric lines is also very convenient for the calculation of the effect of the earth's rotation. In all large ocean currents the vertical movement is small compared with the horizontal movement and as a rule only the horizontal movements need be considered. If the closed curve is placed at right angles to such a movement in which the velocities in the upper and lower isobaric surfaces are $u_0$ and $u_1$, and the distance between the two verticals $L$, then the area projected by the curve on a horizontal surface after unit time has elapsed will be $(u_0 - u_1) L$, and the rate of increase of the projection of the curve on the plane of the Equator will be $(u_0 - u_1) L \sin \phi$, where $\phi$ is the latitude. Denoting the dynamic depths of the lower isobaric surface along the verticals $a$ and $b$ by $D_a$ and $D_b$, equation (4) becomes

$$2\omega \sin \phi \, (u_0 - u_1) L = D_a - D_b$$

or,

$$u_0 - u_1 = \frac{D_a - D_b}{L} \cdot \frac{1}{2\omega \sin \phi} \qquad \text{......(6).}$$

This formula which was developed by Helland-Hansen and Nansen in 1905 (Krümmel, 1911, II, 502) allows the difference between the velocities of the current at two isobaric surfaces to be calculated, and if the water at the lower isobaric surface can be regarded as motionless, it will give the absolute velocity at the upper surface. Generally when the formula is used the water is assumed to be motionless at great depths, and the deepest isobaric surface for which observations are available is regarded as horizontal.

Helland-Hansen and Nansen (1926) have facilitated the application of Bjerknes' theorem to oceanographical problems by constructing charts of *dynamical topography*. If an isobaric surface has the same dynamic depth at two points $a$ and $b$, so that $D_a = D_b$ in equation (6), then the velocity of the water movement at the upper isobaric surface is equal to the velocity at the lower surface, and there is no movement relative to the lower surface at right angles to the line $ab$. If the lower surface is known to be horizontal owing to its being situated at a depth where the water is motionless, the line $ab$, along which the surface has the same dynamic depth, can be regarded as the stream line of the current at the upper surface. If the dynamic depth of a horizontal isobaric surface below a shallower surface is known at a sufficient number of points a chart showing the dynamical topography of the shallow surface can be constructed and the contours or *dynamic isobaths* on the chart give, under the conditions assumed in the specialized form of Bjerknes' theorem, a complete representation of the current stream-lines.

## THE DYNAMICAL TOPOGRAPHY OF THE 0 AND 600 DECIBAR SURFACES IN THE SOUTHERN OCEAN

The topographical charts are based chiefly on the observations made at 106 stations during the circumpolar cruise made by the R.R.S. 'Discovery II' in 1932–33, but in order to make them more complete in the Drake Passage and the Scotia Sea seven series of observations made by the R.R.S. 'William Scoresby' in 1929 have also been used. The report does not aim at giving a complete account of the topography of the isobaric surfaces but only shows the broad outlines; since the 'Discovery II' has made many more observations since 1933 and is still at work, an attempt to produce a very detailed chart would be premature.

The temperature and salinity observations used were made at depths of approximately 0, 10, 20, 30, 40, 50, 60, 80, 100, 150, 200, 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000 m., and then at further intervals of 500 m. down to the sea bottom. The exact depths at which they were made were determined to the nearest 10 m. with the help of depth measurements made with unprotected thermometers, and at most stations, particularly at the greater depths, they were found to differ slightly from the series of standard depths given above.

In treating the data I have followed the procedure of Helland-Hansen[1] using anomalies of specific volume and dynamic depth, but instead of referring them to a sea of uniform temperature 0° C., and salinity 35·00 ‰ I have adopted a standard of temperature 0° C. and density ($\sigma_t$) 28·00. This standard is more convenient for use in the Southern Ocean, giving smaller numbers to work with, and with it the labour of calculating the anomalies was lightened tremendously by the help of a new set of tables given to me in manuscript by Mr D. J. Matthews. The anomalies are generally found by referring to only two tables, with very occasionally a small and simple adjustment from a third table. The tables are drawn up for very small intervals of $\sigma_t$, temperature, and depth, and the necessary interpolations can be made quickly. The tables also give the anomalies to the sixth place of decimals, and since the temperature and salinity data are probably accurate to 0·01° C. and 0·01 $^\circ/_{\circ\circ}$ the anomalies calculated from the tables are likely to be correct to the fifth place of decimals. The anomalies at the standard depths were obtained graphically by plotting those calculated for the thermometrically measured depths against depth on a large-scale graph.

---

[1] The procedure given in a report on the Scientific Results of the 'Michael Sars' North Atlantic Deep-Sea Expedition: Physical Oceanography and Meteorology. The date of publication is not given in the report but references in the text suggest that it was written after 1929.

The positions of the stations at which the observations were made and the anomalies of specific volume and dynamic depth are given in Tables II and III at the end of the report. In order to save space the anomalies of specific volume are given multiplied by $10^6$ and the anomalies of dynamic depth multiplied by $10^5$. The anomalies of dynamic depth can be used in equation (6) since the difference between the anomalies at two stations is equal to the difference between the dynamic depths themselves, and if they are expressed in terms of dynamic metres, with the distance between the two stations $L$ in kilometres, the current difference $u_0 - u_1$ will be obtained in centimetres per second. In order to facilitate the substitution of the data from Table III in equation (6) the values of $\frac{1}{2\omega \sin \phi}$ for latitudes of 30° to 80° are tabulated below; to save space they are multiplied by $10^{-4}$.

Table I. $10^{-4}/2\omega \sin \phi$

| $\phi$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 1·37 | 1·33 | 1·29 | 1·26 | 1·23 | 1·20 | 1·17 | 1·14 | 1·11 | 1·09 |
| 40 | 1·07 | 1·05 | 1·03 | 1·01 | 0·99 | 0·97 | 0·95 | 0·94 | 0·92 | 0·91 |
| 50 | 0·90 | 0·88 | 0·87 | 0·86 | 0·85 | 0·84 | 0·83 | 0·82 | 0·81 | 0·80 |
| 60 | 0·79 | 0·78 | 0·78 | 0·77 | 0·76 | 0·76 | 0·75 | 0·75 | 0·74 | 0·73 |
| 70 | 0·73 | 0·73 | 0·72 | 0·72 | 0·71 | 0·71 | 0·71 | 0·70 | 0·70 | 0·70 |

In Table IV, also given at the end of the report, the dynamic depths of the 0–5000 decibar isobaric surfaces in a sea of uniform temperature 0° C. and density ($\sigma_t$) 28·00 are tabulated, so that the dynamic depths of the isobaric surfaces at any of the stations given in Tables II and III can be obtained by adding the anomalies to these depths.

The topographies of the 0 and 600 decibar surfaces relative to the 3000 surface, obtained by subtracting 0 and the anomalies of dynamic depth of the 600 surface from the anomalies of the 3000 surface, are shown in Figs. 1 and 2. The dynamic isobaths are drawn at intervals of 0·1 dyn. metres and the heavy lines at intervals of 0·5 dyn. metres.

The topographies have been determined relative to the 3000 surface, since at this depth the meridional water movements with which this report is largely concerned are likely to be weakest. Generally the deepest isobaric surface for which observations are available is assumed to be level, but in the Southern Ocean the meridional movements, at least, are probably not weakest near the sea bottom. The work of Defant (1935) in the

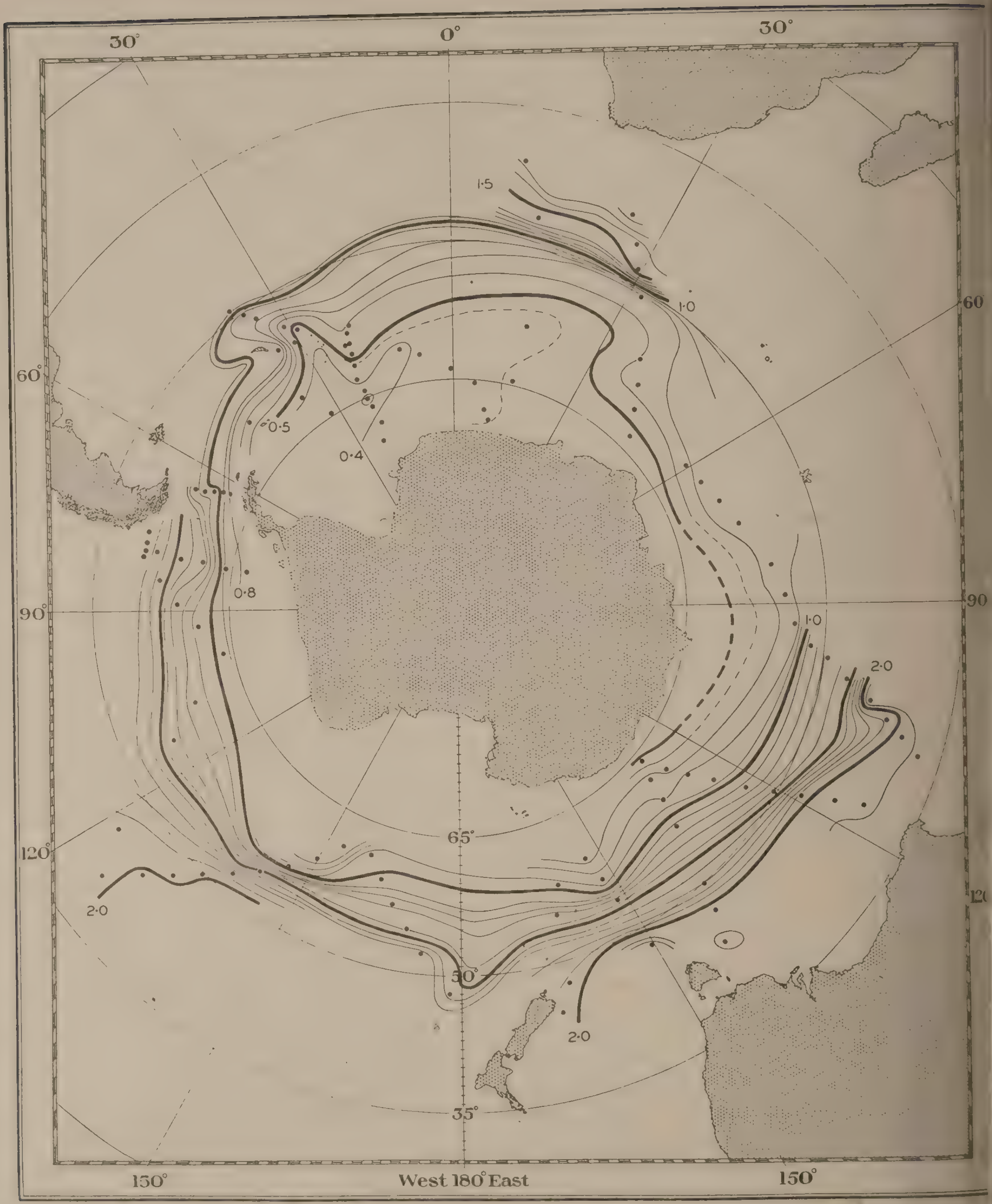
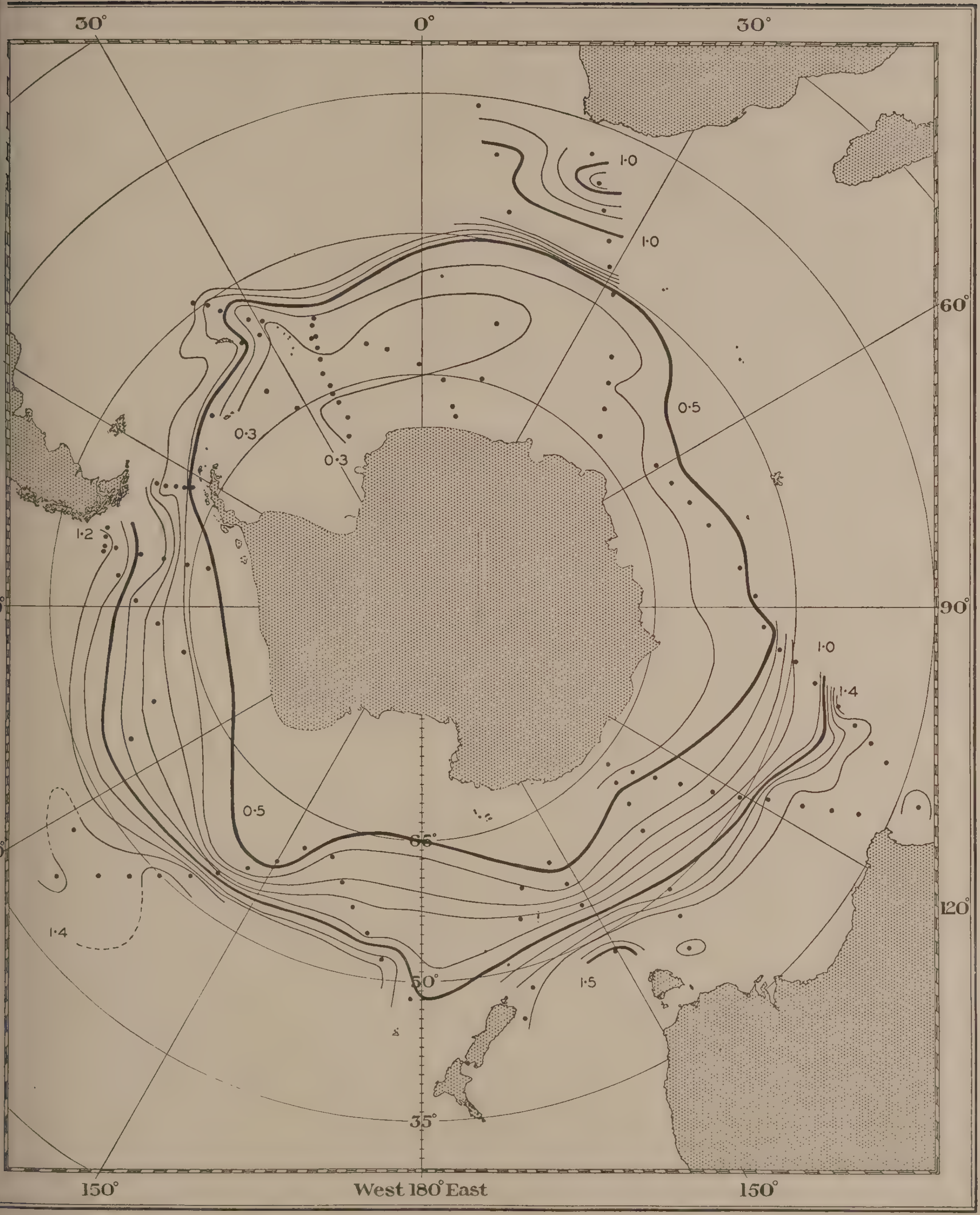

30°
0°
30°
1·5
1·0
60
60°
0·5
0·4
0·8
90°
90
1·0
2·0
120°
12(
65°
2·0
50°
2·0
35°
150°
West 180° East
150°

Fig. 1. The dynamical topography of the 0 decibar surface relative to the 3000 surface. The figures give the anomalies the dynamic depth of the 3000 decibar surface with reference to a sea of uniform temperature 0° C. and density ($\sigma_t$) 28·00, dynamic metres.


30°
0°
30°
1·0
1·0
60°
0·5
0·3
0·3
1·2
90°
1·0
1·4
0·5
65°
120°
1·4
50°
1·5
35°
150°
West 180° East
150°

. 2. The dynamical topography of the 600 decibar surface relative to the 3000 surface. The figures give the differences ween the anomalies of the dynamic depths of the 600 and 3000 decibar surfaces with reference to a sea of uniform temature 0° C. and density ($\sigma_t$) 28·00, in dynamic metres.

southern part of the Atlantic Ocean shows very clearly that the least north or south movement is to be found some distance above the bottom, in the stratum between the southward flowing warm deep current and the northward flowing Antarctic bottom current. The 3000 decibar surface lies rather low in this stratum and principally in the northward bottom current, but since the general eastward movement may, unlike the meridional movement, be weakest near the bottom it seemed advisable to use a surface that was as deep as possible without being in the lowest stratum of the bottom current.

The principal topographical feature of the 0 decibar surface is a downward slope from north to south, the anomalies being highest in the north and lowest near the Antarctic continent. The dynamic isobaths are not always parallel to the lines of latitude, but although they bend successively towards the north and south in different localities their resultant trend, except in the region north of the Weddell Sea, is slightly south of east. If the 3000 decibar surface is level the surface current will have the same trend, but a consideration of the distribution of temperature and salinity in the surface layer and the few available current measurements and drift records fails to support this conclusion, and although the current shows some dependence on the isobaths changing its direction as they alter their course, its main trend appears to differ considerably from theirs.

Where the isobaths bend towards the north the surface current generally has a strong northward movement. Such movements occur north of the Weddell Sea, north-west of the South Sandwich Islands, near the Kerguelen–Gaussberg Ridge, and in 150° W near the Cape Adare–Easter Island Ridge. Where the isobaths bend southwards, in the South Sandwich deep, between 30° E and 40° E, south of Australia, and in the eastern part of the Pacific Ocean, the surface water has a weaker northward movement and it may even have a small trend towards the south (Deacon, 1937, pp. 24–40).

In the Southern Ocean as a whole, however, and not only in the region north of the Weddell Sea, the surface current must have a northward trend. The low temperature and salinity of the surface water in the Antarctic Zone and the low salinity of the surface stratum in the sub-Antarctic Zone show that the surface current must be constantly reinforced by a northward movement from the Antarctic region. It is, in fact, rather doubtful whether the northward movement is completely interrupted even where the isobaths bend sharply southwards: the hydrological conditions in these regions are not very different from those found in the localities where the water is known to spread strongly northwards, and they do not prove more than a weakening of the northward movement.

Owing to the relatively small number of current measurements that have been made in the Southern Ocean there is still some disagreement between the current charts based on them, but the charts given by the most recent workers, Meyer (1923) in the Atlantic Ocean, Michaelis (1923) and Willimzik (1924) in the Indian Ocean, and Merz (Wüst, 1929, p. 41) in the Pacific Ocean, all point to the existence of a northward movement spreading from the Antarctic continent. The northward drift of icebergs and drift-ice affords further evidence of such a movement.

The bulk of the available evidence suggests therefore that the surface current has a more northerly trend than the isobaths: it seems impossible that the water should circumnavigate the Southern Ocean along the same path as the isobaths and it is more reasonable to suppose that it gradually drifts away to the north. The isobaths seem, however, to serve as a measure of the northward movement, bending northwards where it is strong and southwards where it is weak.

The 600 decibar surface (Fig. 2) has a topography similar to that of the 0 surface and the dynamic isobaths of the two are practically parallel. As at the 0 surface the topography suggests that the current flows mainly towards the east, but when allowance has been made for various deviations towards the north and south, the resultant trend in the greater part of the ocean is slightly south of east.

An examination of the temperature and salinity distribution suggests, however, that the topographical chart minimizes the strength of the northward and southward movements. In the Antarctic Zone the 600 decibar surface lies within the vertical limits of the warm deep layer between the colder and less saline surface and bottom layers, and such a layer cannot retain its relatively high temperature and salinity unless it is constantly reinforced by a movement of warm and highly saline water from the north; its presence at any point in the Southern Ocean is therefore a certain indication of the existence of a southward movement.

If the isobaths are regarded as the stream lines of the current they show that the deep water travels round the whole circle of the Southern Ocean without being appreciably diluted by mixing with the colder and less saline surface and bottom waters or reinforced by warm highly saline water from the north, an occurrence which seems most improbable. Vertical mixing must take place as the current flows onwards between the colder and less saline waters and the temperature and salinity will both decrease in the direction of movement. The isotherms and isohalines will therefore lie at an angle to the direction of movement, partly across the current. The temperature of the warmest stratum of the current, an approximate measure of the heat content, is shown in Fig. 3. The current must have some movement towards the south across the isotherms, and since these are approximately parallel to the isobaths (Fig. 2) it follows that the current must also flow southwards across the isobaths. In the Falkland Sector an unqualified acceptance of the isobaths as stream lines of the current leads to the conclusion that the deep water found north of South Georgia, and in 30° W as far north as 46° S is derived, as a result of a current towards the north-east, from the Pacific Ocean (Clowes, 1933), but a survey of the temperature and salinity data shows that a large proportion of it must belong to a southward movement in the Atlantic Ocean (Deacon, 1937, p. 88).

In the southern part of the sub-Antarctic Zone, north of the 0·7–0·8 dynamic metre isobaths in Fig. 2, the water at the level of the 600 decibar surface is a mixture of Antarctic and sub-Antarctic waters sinking towards the north to give rise to the Antarctic intermediate current; but the isobaths have no corresponding northward trend.

Before condemning the isobaths altogether as inaccurate measures of the current direction it must be remembered that those described have shown the topographies of

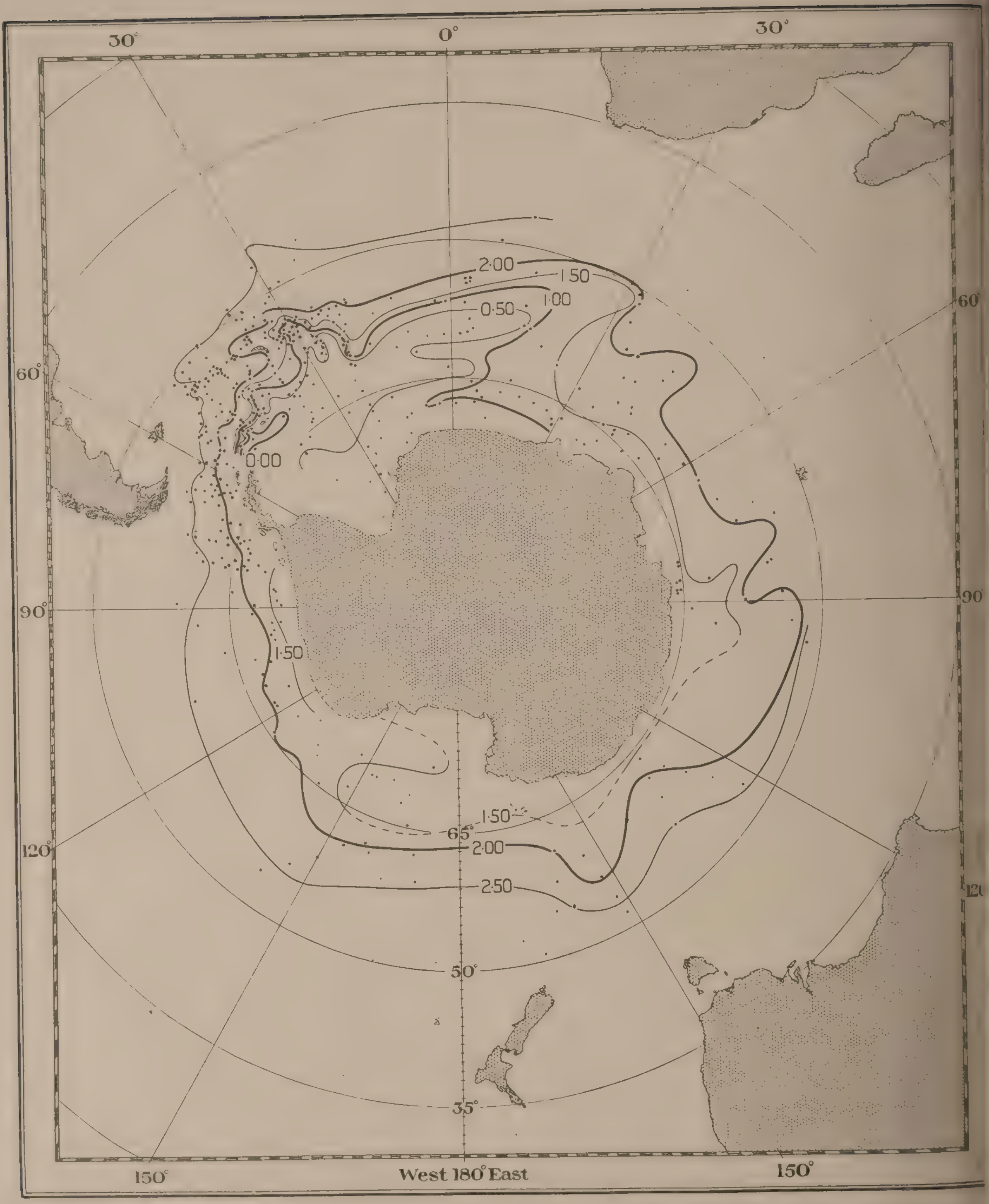

30°
0°
30°
60°
60°
90°
90°
120°
120
150°
West 180° East
150°
2·00
1·50
1·00
0·50
0·00
1·50
1·50
65°
2·00
2·50
50°
35°

Fig. 3. Chart showing the maximum temperature in the warmest stratum of the warm deep current.

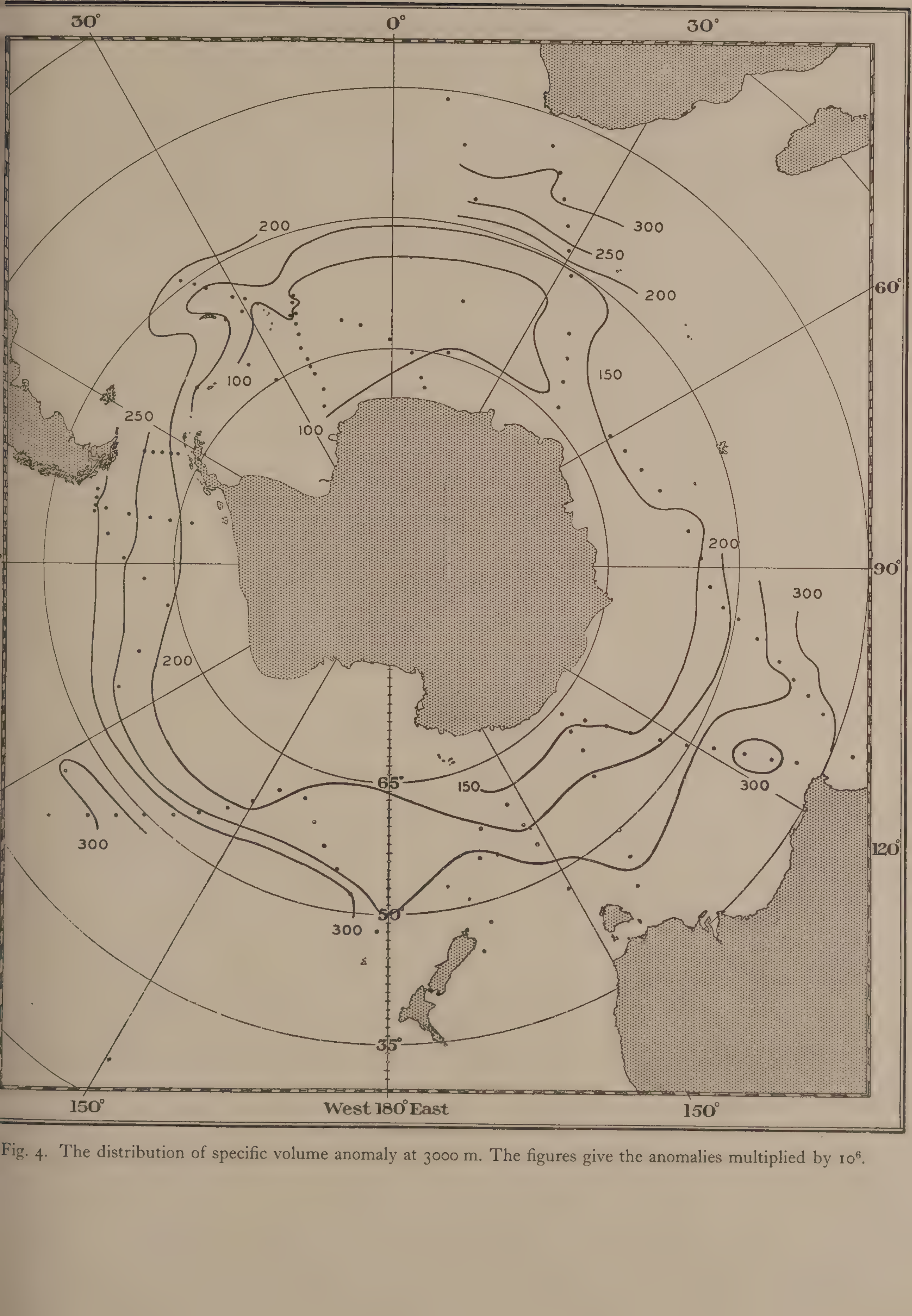

30°
0°
30°
60°
90°
120°
150°
West 180° East
150°
65°
50°
35°
300
250
200
200
150
100
100
250
200
200
300
300
150
300
300
300

Fig. 4. The distribution of specific volume anomaly at 3000 m. The figures give the anomalies multiplied by $10^6$.

the 0 and 600 surfaces relative to the 3000 surface, and if this should have a pronounced slope of its own they cannot be regarded as measures of the absolute current. Under the conditions of stationary equilibrium postulated in the specialized form of Bjerknes' theorem the isobaths of the 3000 decibar surface will be approximately parallel to the lines of equal specific volume anomaly at 3000 m. shown in Fig. 4, and the topography of the surface must be very similar to those of the 0 and 600 surfaces but with much gentler slopes. This being so, the charts showing the topographies of the 0 and 600 surfaces relative to the 3000 surface can be used without serious error as charts of the absolute topographies, and their failure to give accurate representations of the surface and deep current systems implies that the simple equation relating the current difference between two levels to the solenoid field (equation (6), p. 131), developed from the specialized form of Bjerknes' theorem, is not strictly applicable to the conditions of the Southern Ocean.

## THE PROBLEM OF THE MERIDIONAL WATER CIRCULATION IN THE SOUTHERN OCEAN

The derivation of the specialized form of Bjerknes' theorem from the general equation involves two main assumptions: that the current system is in stationary equilibrium so that the circulation has no acceleration, and that the effect of friction is small enough to be neglected. In many parts of the world the results obtained by the application of the specialized theorem justify these assumptions, but the conditions in the Southern Ocean seem to be definitely outstanding and the partial failure of the same methods seems to coincide with conditions which cannot be regarded as stationary, and which are probably more than normally influenced by friction.

On all sides of the Antarctic continent the isosteric surfaces slope downwards to the north, and the fact that they retain this slope unaltered suggests that the principal water movement is a stationary current, flowing horizontally and parallel to the surfaces, towards the east. This is, however, not the only possible movement, since the steady slope of the surfaces does not preclude the existence of the meridional currents suggested by the temperature and salinity distributions—the sinking of the Antarctic surface and the bottom currents towards the north and the climbing of the warm deep current towards the south. Owing to the existence of such currents there will be screwing movements in the main current towards the east, and the meridional circulation will have accelerations that cannot be ignored.

The further treatment of the problem and the evaluation of these accelerations presents great difficulties and has so far not been attempted. Among the factors to be considered is the apparent divergence of the surface and bottom currents from all sides of the Antarctic continent, and the simultaneous convergence of the warm deep current. The problem of a deep current converging from all sides to one point has been considered by Ekman (1928, p. 313) and he points out that the movement in such a system cannot be regarded as proportional to the angle of slope of the isobaric surfaces. Such an assumption would require the existence of a continuous slope around the central region, so that a circumnavigation in a cyclonic direction could only end at a higher level than that from which it was started. A similar argument suggests the possibility that the southward movement of the deep current in the Southern Ocean may be stronger than the small isobaric gradient from east to west seems to allow.

In the Atlantic Antarctic basin the converging and diverging currents are modified by the existence of a large cyclonic whirl, but in the remainder of the Southern Ocean most of the water which flows southwards in the deep current seems to return towards the north in the surface and bottom currents. This type of movement, from one layer to another, is also contrary to the assumption of stationary conditions since it must take place across the isosteric surfaces.

The variations that occur in the inclinations of the paths of the sinking and climbing northward and southward movements—certain to be accompanied by changes of velocity—make the study of the meridional circulation still more interesting. It seems highly probable that the steep gradients found in the neighbourhood of the Antarctic convergence (Deacon, 1934) are a direct consequence of the convergence and divergence of the currents.

When the existence of such a complex circulation is taken into account, and the rather uncertain factors of wind and friction are remembered, it seems unwise to draw conclusions as to the presence, absence, or strength of a water movement from the topographical charts alone, and the use of other methods, particularly to estimate the meridional water movements, becomes a matter of great importance.

## REFERENCES

CLOWES, A. J., 1933. *Influence of the Pacific on the Circulation in the South-West Atlantic Ocean.* Nature, CXXXI, pp. 189–91. London.

DEACON, G. E. R., 1933. *A General Account of the Hydrology of the South Atlantic Ocean.* Discovery Reports, VIII, pp. 171–238, Pls. viii–x. Cambridge.

—— 1934. *Nochmals: Wie entsteht die Antarktische Konvergenz?* Ann. Hydrog. Mar. Meteorol., XII, pp. 475–8, Pl. 61. Hamburg.

—— 1937. *The Hydrology of the Southern Ocean.* Discovery Reports, XV, pp. 1–124, Pls. I–XLIV. Cambridge.

DEFANT, A., 1935. *Zur Dynamik des antarktischen Bodenstromes im Atlantischen Ozean.* Zeitschrift für Geophysik, Jahrg. 11, Heft 1/2, pp. 50–5. Brunswick.

EKMAN, V. W., 1928. *A Survey of some Theoretical Investigations on Ocean Currents.* Journ. du Conseil, III, no. 3, pp. 295–327. Copenhagen.

HELLAND-HANSEN, B. and NANSEN, F., 1926. *The Eastern North Atlantic.* Geofysiske Publikasjoner, IV, no. 2. Oslo.

HESSELBERG, TH. and SVERDRUP, H. U., 1915. *Beitrag zur Berechnung der Druck- und Massenverteilung im Meere.* Bergens Museums Aarbok, 1914–15, nr. 14. Bergen.

KRÜMMEL, O., 1911. Handbuch der Ozeanographie, I, II. Stuttgart.

MEYER, H. H. F., 1923. *Die Oberflächenströmungen des Atlantischen Ozeans im Februar.* Veröffentl. Inst. Meereskunde, XI, pp. 1–35. Berlin.

MICHAELIS, G., 1923. *Die Wasserbewegungen an der Oberfläche des Indischen Ozeans im Januar und Juli.* Veröffentl. Inst. Meereskunde, VIII, pp. 1–32. Berlin.

SANDSTRÖM, J. W. and HELLAND-HANSEN, B., 1903. *Ueber die Berechnung von Meereströmungen.* Report on Norwegian Fishery and Marine Investigations, vol. II, no. 4. Bergen.

SMITH, E. H., 1925. *A Practical Method for determining Ocean Currents.* Coast Guard Bulletin, 14. Washington.

SVERDRUP, H. U., 1933. *Vereinfachtes Verfahren zur Berechnung der Druck- und Massenverteilung im Meere.* Geofysiske Publikasjoner, x, no. 1.

WILLIMZIK, M., 1924. *Die antarktischen Oberflächenströmungen zwischen 50° O und 110° O.* Veröffentl. Inst. Meereskunde, XIII, pp. 25–9. Berlin.

WÜST, G., 1924. *Florida- und Antillenstrom, eine hydrodynamische Untersuchung.* Veröffentl. Inst. Meereskunde, XII, pp. 1–48, Berlin.

—— 1929. *Schichtung und Tiefenzirkulation des Pazifischen Ozeans.* Veröffentl. Inst. Meereskunde, XX, pp. 1–64. Berlin.

## Table II

| Station | Position | |
|---|---|---|
| | Latitude | Longitude |
| | South | West |
| 805 | 56° 41·4′ | 20° 38·2′ |
| 806 | 57° 27·2′ | 21° 28·8′ |
| 807 | 58° 47·7′ | 21° 40·4′ |
| 808 | 59° 56·0′ | 22° 20·7′ |
| 809 | 61° 09·9′ | 22° 36·9′ |
| 811 | 62° 44·0′ | 23° 18·4′ |
| 812 | 64° 12·5′ | 22° 57·0′ |
| 813 | 64° 55·9′ | 23° 13·0′ |
| 814 | 66° 02·8′ | 22° 35·1′ |
| 816 | 68° 09·6′ | 22° 01·7′ |
| 817 | 69° 59·0′ | 23° 53·0′ |
| 821 | 65° 00·5′ | 32° 32·8′ |
| 823 | 61° 24·4′ | 36° 03·6′ |
| | South | East |
| 847 | 43° 07·4′ | 25° 04·6′ |
| 848 | 45° 48·4′ | 27° 13·6′ |
| 849 | 48° 14·6′ | 29° 23·7′ |
| 850 | 50° 43·8′ | 31° 44·0′ |
| 851 | 56° 22·1′ | 37° 22·3′ |
| 852 | 58° 39·5′ | 40° 03·9′ |
| 853 | 61° 00·2′ | 43° 11·1′ |
| 854 | 63° 30·2′ | 46° 24·9′ |
| 857 | 60° 40·1′ | 59° 23·7′ |
| 858 | 60° 10·1′ | 63° 54·8′ |
| 859 | 59° 19·1′ | 68° 51·8′ |
| 860 | 57° 56·4′ | 73° 58·8′ |
| 862 | 55° 33·8′ | 83° 00·4′ |
| 863 | 54° 15·3′ | 88° 22·4′ |
| 864 | 53° 11·7′ | 93° 10·6′ |
| 866 | 51° 22·6′ | 96° 26·4′ |
| 867 | 49° 25·5′ | 98° 21·8′ |
| 868 | 46° 55·4′ | 100° 45·6′ |
| 869 | 43° 56·5′ | 103° 24·3′ |
| 870 | 41° 41·7′ | 105° 16·0′ |
| 871 | 39° 32·1′ | 107° 06·4′ |
| 872 | 37° 09·1′ | 108° 47·2′ |
| 879 | 40° 56·7′ | 116° 46·5′ |
| 880 | 43° 53·1′ | 117° 50·8′ |
| 881 | 47° 00·0′ | 119° 00·3′ |
| 882 | 49° 52·9′ | 120° 28·6′ |
| 883 | 52° 54·0′ | 122° 03·8′ |
| 884 | 56° 08·3′ | 124° 04·8′ |
| 885 | 58° 50·5′ | 125° 54·9′ |
| 886 | 61° 12·1′ | 127° 52·9′ |
| 887 | 63° 41·4′ | 130° 07·0′ |
| 889 | 61° 44·6′ | 131° 38·4′ |
| 890 | 59° 04·5′ | 133° 18·5′ |
| 891 | 56° 02·9′ | 135° 10·5′ |
| 893 | 49° 37·5′ | 138° 35·3′ |
| 894 | 46° 31·5′ | 139° 50·0′ |
| 895 | 43° 15·5′ | 141° 38·4′ |
| 899 | 47° 18·2′ | 150° 20·8′ |
| 903 | 53° 32·0′ | 151° 33·4′ |
| 904 | 56° 13·1′ | 152° 15·8′ |
| 905 | 59° 11·6′ | 153° 17·4′ |
| 919 | 61° 18·2′ | 155° 37·1′ |
| 920 | 61° 05·0′ | 158° 24·5′ |
| 923 | 61° 02·0′ | 158° 26·0′ |
| 924 | 60° 20·0′ | 158° 52·9′ |
| | South | West |
| 944 | 47° 41·6′ | 178° 16·0′ |
| 947 | 51° 59·2′ | 173° 26·9′ |
| 948 | 54° 24·9′ | 170° 13·0′ |
| 949 | 56° 49·6′ | 166° 55·9′ |
| 950 | 59° 05·3′ | 163° 46·5′ |
| 951 | 61° 26·3′ | 160° 02·9′ |
| 959 | 61° 07·0′ | 153° 57·2′ |
| 960 | 58° 31·4′ | 150° 02·9′ |
| 961 | 56° 16·4′ | 146° 22·3′ |
| 962 | 54° 02·8′ | 142° 25·4′ |
| 963 | 52° 01·1′ | 139° 13·2′ |
| 964 | 49° 42·1′ | 135° 33·2′ |
| 965 | 47° 16·9′ | 132° 25·1′ |
| 966 | 44° 40·3′ | 129° 27·9′ |
| 967 | 41° 03·1′ | 126° 03·9′ |
| 969 | 45° 36·1′ | 122° 09·5′ |
| 970 | 55° 26·7′ | 115° 00·8′ |
| 972 | 59° 21·8′ | 109° 59·5′ |
| 974 | 63° 57·0′ | 101° 16·0′ |
| 975 | 61° 29·9′ | 94° 06·7′ |
| 976 | 59° 22·0′ | 89° 03·9′ |
| 977 | 57° 18·2′ | 84° 29·5′ |
| 978 | 55° 18·4′ | 80° 08·1′ |
| 983 | 55° 10·0′ | 76° 04·7′ |
| 984 | 55° 14·4′ | 77° 48·6′ |
| 985 | 55° 20·2′ | 79° 24·5′ |
| 986 | 56° 28·9′ | 79° 28·2′ |
| 988 | 59° 19·0′ | 79° 39·8′ |
| 990 | 61° 56·3′ | 79° 57·0′ |
| 992 | 64° 19·2′ | 80° 06·0′ |
| 994 | 66° 45·7′ | 80° 19·8′ |
| 1049 | 54° 49·7′ | 29° 35·4′ |
| 1050 | 53° 46·6′ | 31° 09·2′ |
| 1053 | 51° 09·4′ | 34° 35·3′ |
| 1054 | 50° 07·8′ | 35° 48·6′ |
| 1055 | 49° 03·2′ | 37° 16·7′ |
| 1138 | 55° 55·5′ | 31° 15·6′ |
| 1142 | 58° 44·3′ | 22° 30·9′ |
| 1146 | 61° 00·2′ | 12° 03·8′ |
| 1147 | 61° 49·7′ | 08° 09·9′ |
| 1148 | 63° 52·0′ | 00° 54·9′ |
| | South | East |
| 1150 | 65° 21·6′ | 04° 33·7′ |
| 1152 | 68° 03·0′ | 08° 03·0′ |
| 1154 | 69° 20·8′ | 09° 33·8′ |
| 1156 | 64° 43·3′ | 14° 41·4′ |
| 1158 | 58° 37·5′ | 14° 42·7′ |
| 1162 | 46° 47·2′ | 12° 39·4′ |
| 1165 | 41° 01·0′ | 09° 34·3′ |
| | South | West |
| WS 365 | 55° 52′ 10″ | 33° 53′ 00″ |
| WS 379 | 59° 35′ 00″ | 47° 15′ 00″ |
| WS 400 | 62° 07′ 00 ′ | 62° 33′ 00″ |
| WS 401 | 61° 20′ 00″ | 63° 12′ 00″ |
| WS 402 | 60° 32′ 00″ | 63° 57′ 00″ |
| WS 403 | 59° 40′ 00″ | 64° 35′ 00″ |
| WS 404 | 58° 49′ 00″ | 65° 15′ 00″ |

## Table III

A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28, 0, P})$

| Pressure decibars | Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 805 | 806 | 807 | 808 | 809 | 811 | 812 | 813 | 814 | 816 | 817 | 821 | 823 |
| 0 | 1033 | 976 | 1090 | 1014 | 1507 | 833 | 729 | 976 | 776 | 1175 | 957 | 795 | 1517 |
| 10 | 1033 | 928 | 1071 | 938 | 1488 | 833 | 729 | 976 | 748 | 1175 | 957 | 795 | 1517 |
| 20 | 1032 | 928 | 1052 | 900 | 728 | 794 | 502 | 681 | 682 | 349 | 720 | 435 | 1507 |
| 30 | 975 | 928 | 984 | 842 | 596 | 454 | 463 | 463 | 491 | 273 | 340 | 283 | 681 |
| 40 | 927 | 889 | 812 | 747 | 519 | 320 | 339 | 301 | 339 | 272 | 339 | 272 | 585 |
| 50 | 747 | 785 | 718 | 654 | 434 | 281 | 301 | 272 | 272 | 244 | 310 | 253 | 386 |
| 60 | 662 | 691 | 633 | 624 | 366 | 271 | 233 | 233 | 252 | 243 | 281 | 252 | 328 |
| 80 | 633 | 633 | 593 | 576 | 318 | 261 | 223 | 232 | 232 | 224 | 252 | 204 | 270 |
| 100 | 574 | 574 | 497 | 527 | 297 | 239 | 184 | 192 | 202 | 213 | 213 | 191 | 268 |
| 150 | 508 | 463 | 375 | 431 | 238 | 228 | 151 | 167 | 152 | 163 | 191 | 182 | 247 |
| 200 | 354 | 356 | 283 | 320 | 212 | 178 | 162 | 153 | 154 | 165 | 185 | 159 | 184 |
| 300 | 275 | 297 | 213 | 232 | 153 | 173 | 144 | 145 | 155 | 165 | 179 | 144 | 178 |
| 400 | 251 | 281 | 177 | 230 | 144 | 145 | 126 | 145 | 145 | 156 | 166 | 144 | 143 |
| 600 | 229 | 239 | 179 | 184 | 146 | 146 | 138 | 145 | 137 | 158 | 170 | 137 | 146 |
| 800 | 202 | 180 | 170 | 180 | 148 | 147 | 127 | 147 | 147 | 148 | 152 | 147 | 136 |
| 1000 | 174 | 161 | 169 | 177 | 136 | 135 | 116 | 135 | 136 | 147 | 142 | 136 | 135 |
| 1500 | 151 | 153 | 156 | 145 | 130 | 121 | 119 | 128 | 121 | 143 | 137 | 120 | 123 |
| 2000 | 143 | 142 | 138 | 138 | 113 | 111 | 98 | 117 | 111 | 133 | 119 | 102 | 103 |
| 2500 | 128 | 121 | 117 | 117 | 99 | 101 | 89 | 98 | 100 | 112 | 109 | 89 | 77 |
| 3000 | 96 | 128 | 92 | 94 | 88 | 90 | 88 | 90 | 92 | 93 | 99 | 83 | 69 |
| 3500 | 83 | — | 80 | — | 76 | — | 82 | — | 81 | — | 90 | 81 | — |
| 4000 | — | — | — | — | 53 | — | 66 | — | 72 | — | 83 | — | — |
| 4500 | — | — | — | — | — | — | 44 | — | 57 | — | — | — | — |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |

B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28, 0, P})$ dynamic metres

| Pressure decibars | 805 | 806 | 807 | 808 | 809 | 811 | 812 | 813 | 814 | 816 | 817 | 821 | 823 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1033 | 952 | 1081 | 976 | 1498 | 833 | 729 | 976 | 762 | 1175 | 957 | 795 | 1517 |
| 20 | 2066 | 1880 | 2143 | 1895 | 2606 | 1647 | 1345 | 1804 | 1477 | 1937 | 1795 | 1410 | 3029 |
| 30 | 3069 | 2808 | 3161 | 2766 | 3268 | 2271 | 1827 | 2376 | 2064 | 2248 | 2325 | 1769 | 4123 |
| 40 | 4020 | 3717 | 4059 | 3561 | 3825 | 2658 | 2228 | 2758 | 2479 | 2521 | 2664 | 2047 | 4756 |
| 50 | 4857 | 4554 | 4824 | 4261 | 4302 | 2958 | 2548 | 3039 | 2784 | 2779 | 2989 | 2309 | 5242 |
| 60 | 5562 | 5292 | 5500 | 4900 | 4702 | 3234 | 2815 | 3292 | 3046 | 3022 | 3284 | 2562 | 5599 |
| 80 | 6856 | 6616 | 6726 | 6100 | 5386 | 3766 | 3271 | 3756 | 3530 | 3490 | 3818 | 3018 | 6187 |
| 100 | 8064 | 7822 | 7816 | 7202 | 6002 | 4266 | 3677 | 4180 | 3964 | 3926 | 4282 | 3414 | 6725 |
| 150 | 10769 | 10417 | 9996 | 9597 | 7337 | 5436 | 4517 | 5075 | 4849 | 4866 | 5292 | 4344 | 7010 |
| 200 | 12924 | 12462 | 11641 | 11477 | 8462 | 6451 | 5297 | 5875 | 5614 | 5686 | 6232 | 5194 | 8090 |
| 300 | 16074 | 15732 | 14121 | 14237 | 10292 | 8211 | 6827 | 7365 | 7164 | 7336 | 8052 | 6714 | 9900 |
| 400 | 18704 | 18622 | 16071 | 16547 | 11772 | 9801 | 8177 | 8815 | 8664 | 8946 | 9782 | 8154 | 11500 |
| 600 | 23504 | 23822 | 19631 | 20687 | 14672 | 12701 | 10817 | 11715 | 11484 | 12086 | 13142 | 10954 | 14400 |
| 800 | 27824 | 28002 | 23111 | 24327 | 17612 | 15641 | 13477 | 14635 | 14324 | 15146 | 16362 | 13794 | 17220 |
| 1000 | 31584 | 31402 | 26511 | 27887 | 20452 | 18461 | 15897 | 17455 | 17144 | 18086 | 19302 | 16634 | 19920 |
| 1500 | 39684 | 39252 | 34611 | 35937 | 27102 | 24861 | 21797 | 24055 | 23594 | 25336 | 26252 | 23034 | 26370 |
| 2000 | 47034 | 46652 | 41961 | 42987 | 33202 | 30661 | 27197 | 30155 | 29394 | 32236 | 32652 | 28584 | 32020 |
| 2500 | 53784 | 53202 | 48361 | 49387 | 38502 | 35961 | 31897 | 35555 | 34644 | 38386 | 38352 | 33334 | 36520 |
| 3000 | 59384 | 59452 | 53561 | 54637 | 43152 | 40711 | 36297 | 40255 | 39444 | 43486 | 43552 | 37634 | 40170 |
| 3500 | 63884 | — | 57861 | — | 47252 | — | 40547 | — | 43794 | — | 48302 | 41734 | — |
| 4000 | — | — | — | — | 50502 | — | 44247 | — | 47594 | — | 52602 | — | — |
| 4500 | — | — | — | — | — | — | 46997 | — | 50844 | — | — | — | — |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |

## Table III (*cont.*)

| Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 848 | 849 | 850 | 851 | 852 | 853 | 854 | 857 | 858 | 859 | 860 | 862 | 863 | 864 |
| A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28,0,P})$ | | | | | | | | | | | | | |
| 1365 | 1308 | 739 | 805 | 767 | 739 | 597 | 786 | 833 | 843 | 833 | 843 | 871 | 947 |
| 1367 | 1310 | 740 | 805 | 767 | 739 | 597 | 786 | 833 | 843 | 833 | 843 | 872 | 948 |
| 1360 | 1312 | 741 | 805 | 767 | 739 | 597 | 786 | 833 | 833 | 833 | 844 | 872 | 949 |
| 1361 | 1313 | 741 | 806 | 767 | 739 | 597 | 786 | 834 | 834 | 833 | 843 | 873 | 948 |
| 1363 | 1325 | 741 | 805 | 767 | 738 | 595 | 785 | 833 | 833 | 833 | 844 | 863 | 949 |
| 1364 | 1289 | 741 | 805 | 767 | 738 | 595 | 785 | 833 | 833 | 833 | 845 | 815 | 950 |
| 1365 | 1291 | 742 | 795 | 767 | 738 | 462 | 785 | 824 | 833 | 833 | 846 | 816 | 951 |
| 1349 | 1294 | 743 | 787 | 718 | 517 | 248 | 574 | 825 | 796 | 834 | 846 | 721 | 951 |
| 1322 | 1298 | 733 | 759 | 508 | 432 | 230 | 525 | 650 | 641 | 707 | 694 | 617 | 924 |
| 1031 | 1112 | 637 | 453 | 416 | 353 | 213 | 391 | 517 | 529 | 558 | 488 | 546 | 754 |
| 941 | 1030 | 501 | 399 | 346 | 302 | 187 | 330 | 431 | 422 | 442 | 426 | 454 | 532 |
| 866 | 938 | 322 | 320 | 305 | 264 | 181 | 392 | 373 | 370 | 383 | 327 | 401 | 364 |
| 815 | 840 | 275 | 269 | 282 | 250 | 175 | 331 | 332 | 331 | 333 | 305 | 326 | 288 |
| 737 | 760 | 239 | 251 | 214 | 210 | 159 | 215 | 375 | 291 | 294 | 263 | 264 | 263 |
| 640 | 650 | 228 | 218 | 203 | 185 | 153 | 206 | 238 | 229 | 255 | 234 | 264 | 207 |
| 561 | 534 | 220 | 216 | 206 | 170 | 160 | 201 | 225 | 226 | 226 | 201 | 232 | 205 |
| 394 | 381 | 170 | 237 | 174 | 159 | 147 | 192 | 202 | 204 | 204 | 204 | 215 | 203 |
| 324 | 300 | 156 | 158 | 153 | 153 | 136 | 175 | 184 | 184 | 187 | 197 | 229 | 192 |
| 304 | 293 | 151 | 156 | 146 | 146 | 114 | 162 | 185 | 171 | 171 | 175 | 201 | 180 |
| 285 | 242 | 123 | 134 | 134 | 122 | 102 | 151 | 159 | 154 | 168 | 139 | 151 | 160 |
| 248 | 214 | 95 | 119 | 114 | 107 | 89 | 137 | 133 | 138 | — | — | 129 | 140 |
| 204 | 191 | 83 | 99 | 98 | 94 | 74 | — | 105 | 92 | — | — | 120 | 118 |
| 173 | 164 | 81 | 81 | 88 | 80 | — | — | 100 | — | — | — | — | — |
| 147 | 140 | 80 | — | 69 | 65 | — | — | — | — | — | — | — | — |
| B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28,0,P})$ dynamic metres | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1366 | 1309 | 740 | 805 | 767 | 739 | 597 | 786 | 833 | 843 | 833 | 843 | 872 | 948 |
| 2729 | 2620 | 1480 | 1610 | 1534 | 1478 | 1194 | 1572 | 1666 | 1681 | 1666 | 1687 | 1744 | 1896 |
| 4090 | 3932 | 2221 | 2416 | 2301 | 2217 | 1791 | 2358 | 2500 | 2514 | 2499 | 2530 | 2616 | 2845 |
| 5452 | 5251 | 2962 | 3221 | 3068 | 2955 | 2387 | 3143 | 3333 | 3348 | 3332 | 3374 | 3484 | 3793 |
| 6815 | 6558 | 3703 | 4026 | 3835 | 3693 | 2982 | 3928 | 4166 | 4181 | 4165 | 4218 | 4323 | 4743 |
| 8180 | 7848 | 4445 | 4826 | 4602 | 4431 | 3510 | 4713 | 4995 | 5014 | 4998 | 5063 | 5139 | 5693 |
| 10894 | 10434 | 5929 | 6408 | 6088 | 5687 | 4220 | 6073 | 6643 | 6642 | 6664 | 6755 | 6675 | 7595 |
| 13564 | 13026 | 7405 | 7954 | 7314 | 6635 | 4698 | 7171 | 8119 | 8080 | 8206 | 8295 | 8013 | 9471 |
| 19444 | 19051 | 10830 | 10984 | 9624 | 8600 | 5808 | 9461 | 11034 | 11005 | 11366 | 11250 | 10918 | 13666 |
| 24374 | 24406 | 13675 | 13114 | 11529 | 10235 | 6808 | 11261 | 13404 | 13380 | 13866 | 13535 | 13418 | 16881 |
| 33414 | 34246 | 17795 | 16714 | 14779 | 13065 | 8648 | 14871 | 17424 | 17340 | 17986 | 17285 | 17698 | 21361 |
| 41814 | 43136 | 20775 | 19654 | 17719 | 15635 | 10428 | 18491 | 20954 | 20840 | 21566 | 20445 | 21328 | 24621 |
| 57334 | 59136 | 25915 | 24854 | 22679 | 20235 | 13768 | 23951 | 28014 | 27060 | 27846 | 26125 | 27228 | 30121 |
| 71114 | 73236 | 30595 | 29554 | 26839 | 24175 | 16888 | 28151 | 34134 | 32260 | 33326 | 31085 | 32508 | 34821 |
| 83114 | 85076 | 35075 | 33894 | 30939 | 27735 | 20008 | 32231 | 38774 | 36820 | 38126 | 35445 | 37468 | 38941 |
| 107014 | 107976 | 44825 | 35024 | 40439 | 35935 | 27708 | 42031 | 49424 | 47570 | 48876 | 45545 | 48618 | 49141 |
| 124964 | 124976 | 52975 | 44874 | 48589 | 43735 | 34758 | 51231 | 59074 | 57270 | 58626 | 55595 | 59718 | 59041 |
| 140664 | 139826 | 60625 | 52724 | 56089 | 51235 | 41008 | 59631 | 68274 | 66170 | 67576 | 64895 | 70468 | 68341 |
| 155364 | 153176 | 67475 | 59974 | 63089 | 57935 | 46408 | 67481 | 76874 | 74270 | 76026 | 72745 | 79268 | 76841 |
| 168714 | 164576 | 72925 | 66324 | 69289 | 63635 | 51208 | 74681 | 84174 | 81570 | — | — | 86268 | 84341 |
| 180014 | 174726 | 77375 | 71774 | 74589 | 68685 | 55258 | — | 90124 | 87320 | — | — | 92518 | 90791 |
| 189414 | 183576 | 81475 | 76274 | 79239 | 73035 | — | — | 95224 | — | — | — | — | — |
| 197414 | 191176 | 85475 | — | 83139 | 76685 | — | — | — | — | — | — | — | — |

## Table III (*cont.*)

A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28,0,P})$

| Pressure decibars | Stations<br>866 | 867 | 868 | 869 | 870 | 871 | 872 | 879 | 880 | 881 | 882 | 883 | 884 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1023 | 1194 | 1308 | 1346 | 1450 | 1479 | 1697 | 1488 | 1375 | 1403 | 1128 | 1023 | 833 |
| 10 | 1024 | 1196 | 1310 | 1348 | 1452 | 1491 | 1701 | 1491 | 1377 | 1405 | 1130 | 1024 | 834 |
| 20 | 1025 | 1198 | 1322 | 1351 | 1455 | 1494 | 1693 | 1494 | 1380 | 1407 | 1131 | 1025 | 834 |
| 30 | 1025 | 1198 | 1322 | 1352 | 1456 | 1496 | 1697 | 1495 | 1381 | 1408 | 1132 | 1025 | 835 |
| 40 | 1026 | 1199 | 1304 | 1355 | 1459 | 1509 | 1653 | 1498 | 1384 | 1410 | 1133 | 1026 | 834 |
| 50 | 1027 | 1200 | 1296 | 1357 | 1461 | 1502 | 1655 | 1501 | 1386 | 1412 | 1134 | 1027 | 835 |
| 60 | 1028 | 1201 | 1288 | 1357 | 1463 | 1504 | 1649 | 1504 | 1388 | 1414 | 1135 | 1028 | 836 |
| 80 | 1019 | 1194 | 1261 | 1363 | 1467 | 1499 | 1664 | 1509 | 1381 | 1408 | 1137 | 1029 | 837 |
| 100 | 1020 | 1197 | 1264 | 1368 | 1472 | 1456 | 1651 | 1408 | 1386 | 1412 | 1139 | 1030 | 837 |
| 150 | 958 | 1075 | 1157 | 1179 | 1225 | 1173 | 1302 | 1219 | 1291 | 1196 | 943 | 794 | 801 |
| 200 | 773 | 979 | 1103 | 1226 | 1158 | 1131 | 1264 | 1145 | 1128 | 1185 | 926 | 728 | 560 |
| 300 | 701 | 849 | 888 | 1132 | 1149 | 1142 | 1179 | 1101 | 1149 | 1139 | 877 | 639 | 438 |
| 400 | 608 | 762 | 847 | 1142 | 1140 | 1138 | 1197 | 1109 | 1138 | 1108 | 781 | 599 | 389 |
| 600 | 516 | 638 | 686 | 1163 | 1122 | 1107 | 1134 | 1110 | 1125 | 1012 | 692 | 469 | 320 |
| 800 | 432 | 524 | 588 | 1106 | 968 | 982 | 1106 | 1061 | 1060 | 843 | 553 | 375 | 277 |
| 1000 | 368 | 436 | 503 | 905 | 788 | 801 | 883 | 825 | 861 | 715 | 488 | 340 | 267 |
| 1500 | 275 | 329 | 350 | 573 | 505 | 532 | 554 | 541 | 552 | 470 | 359 | 290 | 249 |
| 2000 | 263 | 293 | 293 | 437 | 393 | 420 | 406 | 422 | 407 | 372 | 297 | 265 | 218 |
| 2500 | 231 | 252 | 253 | 352 | 312 | 339 | 320 | 357 | 362 | 315 | 267 | 236 | 189 |
| 3000 | 190 | 213 | 248 | 287 | 252 | 291 | 290 | 330 | 312 | 292 | 241 | 199 | 150 |
| 3500 | — | — | — | 279 | 202 | 237 | 262 | 299 | 282 | 266 | 215 | 175 | 127 |
| 4000 | — | — | — | — | — | — | — | 247 | 254 | — | — | — | 114 |
| 4500 | — | — | — | — | — | — | — | 240 | — | — | — | — | 113 |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |

B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28,0,P})$ dynamic metres

| Pressure decibars | 866 | 867 | 868 | 869 | 870 | 871 | 872 | 879 | 880 | 881 | 882 | 883 | 884 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1023 | 1195 | 1309 | 1347 | 1451 | 1485 | 1699 | 1490 | 1376 | 1404 | 1129 | 1024 | 834 |
| 20 | 2048 | 2392 | 2625 | 2696 | 2905 | 2977 | 3396 | 2982 | 2755 | 2810 | 2259 | 2048 | 1668 |
| 30 | 3073 | 3590 | 3947 | 4048 | 4360 | 4472 | 5091 | 4477 | 4135 | 4217 | 3391 | 3073 | 2502 |
| 40 | 4098 | 4789 | 5260 | 5401 | 5818 | 5975 | 6766 | 5973 | 5518 | 5626 | 4523 | 4099 | 3337 |
| 50 | 5125 | 5988 | 6560 | 6757 | 7278 | 7480 | 8420 | 7473 | 6903 | 7037 | 5657 | 5125 | 4171 |
| 60 | 6152 | 7189 | 7852 | 8114 | 8740 | 8983 | 10072 | 8975 | 8290 | 8450 | 6791 | 6153 | 5007 |
| 80 | 8200 | 9583 | 10402 | 10834 | 11670 | 11987 | 13386 | 11989 | 11058 | 11272 | 9063 | 8209 | 6679 |
| 100 | 10238 | 11975 | 12926 | 13566 | 14608 | 14941 | 16700 | 14905 | 13826 | 14092 | 11339 | 10269 | 8353 |
| 150 | 15183 | 17655 | 18981 | 19931 | 21353 | 21516 | 24080 | 21475 | 20516 | 20612 | 16544 | 14829 | 12448 |
| 200 | 19508 | 22790 | 24631 | 25946 | 27308 | 27276 | 30495 | 27385 | 26566 | 26567 | 21214 | 18634 | 15848 |
| 300 | 26878 | 31930 | 34591 | 37736 | 38848 | 38636 | 42715 | 38615 | 37956 | 38187 | 30234 | 25464 | 20838 |
| 400 | 33428 | 39980 | 43271 | 49106 | 50288 | 50036 | 54595 | 49665 | 49386 | 49427 | 38524 | 31654 | 24978 |
| 600 | 44668 | 53980 | 58591 | 72166 | 72908 | 72496 | 77915 | 71865 | 72026 | 70627 | 53244 | 42334 | 32058 |
| 800 | 54148 | 65600 | 71331 | 94846 | 93808 | 93376 | 100315 | 93565 | 93866 | 89187 | 65704 | 50774 | 38038 |
| 1000 | 62148 | 75200 | 82251 | 114966 | 111368 | 111216 | 120215 | 112425 | 113086 | 104767 | 76104 | 57934 | 43478 |
| 1500 | 78248 | 94350 | 103551 | 151916 | 143718 | 144516 | 156115 | 146575 | 148886 | 134417 | 97304 | 73684 | 56378 |
| 2000 | 91698 | 109900 | 119651 | 177166 | 166168 | 168316 | 180115 | 170675 | 172886 | 155467 | 113704 | 87534 | 68028 |
| 2500 | 104048 | 123500 | 133301 | 196866 | 183768 | 187316 | 198265 | 190175 | 192086 | 172617 | 127804 | 100084 | 78228 |
| 3000 | 114548 | 135150 | 145851 | 212866 | 197868 | 203066 | 213515 | 207325 | 208936 | 187817 | 140504 | 110934 | 86728 |
| 3500 | — | — | — | 227016 | 209218 | 216266 | 227315 | 223075 | 223786 | 201767 | 151904 | 120284 | 93628 |
| 4000 | — | — | — | — | — | — | — | 236725 | 237186 | — | — | — | 99678 |
| 4500 | — | — | — | — | — | — | — | 248875 | — | — | — | — | 105328 |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |

## Table III (*cont.*)

| Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 886 | 887 | 889 | 890 | 891 | 893 | 894 | 895 | 899 | 903 | 904 | 905 | 919 | 920 |
| A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28, 0, P})$ | | | | | | | | | | | | | |
| 644 | 616 | 682 | 758 | 938 | 1280 | 1327 | 1356 | 1261 | 1147 | 909 | 720 | 900 | 957 |
| 644 | 616 | 682 | 758 | 939 | 1282 | 1329 | 1359 | 1263 | 1149 | 910 | 720 | 900 | 958 |
| 644 | 615 | 682 | 758 | 940 | 1284 | 1332 | 1362 | 1266 | 1150 | 910 | 720 | 901 | 958 |
| 643 | 615 | 682 | 759 | 939 | 1285 | 1333 | 1364 | 1267 | 1140 | 910 | 719 | 900 | 958 |
| 642 | 604 | 681 | 758 | 940 | 1287 | 1335 | 1355 | 1270 | 1141 | 910 | 718 | 901 | 959 |
| 642 | 604 | 681 | 758 | 941 | 1278 | 1337 | 1357 | 1272 | 1143 | 911 | 718 | 901 | 960 |
| 642 | 565 | 681 | 758 | 942 | 1279 | 1338 | 1359 | 1274 | 1144 | 912 | 718 | 902 | 960 |
| 641 | 314 | 681 | 749 | 942 | 1273 | 1343 | 1355 | 1278 | 1136 | 903 | 642 | 893 | 961 |
| 631 | 268 | 682 | 749 | 934 | 1287 | 1329 | 1350 | 1282 | 1062 | 837 | 381 | 884 | 963 |
| 410 | 261 | 512 | 529 | 725 | 1171 | 1089 | 1227 | 1220 | 922 | 620 | 300 | 716 | 966 |
| 365 | 224 | 443 | 490 | 774 | 1100 | 1098 | 1146 | 1137 | 870 | 530 | 274 | 643 | 895 |
| 279 | 228 | 383 | 413 | 770 | 1052 | 1077 | 1132 | 1108 | 800 | 440 | 250 | 534 | 800 |
| 255 | 194 | 343 | 344 | 700 | 1007 | 1085 | 1092 | 1104 | 708 | 414 | 256 | 455 | 675 |
| 254 | 174 | 274 | 316 | 468 | 840 | 1102 | 1094 | 1131 | 600 | 300 | 235 | 379 | 600 |
| 205 | 177 | 266 | 288 | 384 | 732 | 1049 | 990 | 1110 | 530 | 298 | 233 | 325 | 525 |
| 200 | 161 | 234 | 239 | 345 | 652 | 873 | 745 | 1152 | 464 | 304 | 226 | 305 | 434 |
| 176 | 160 | 215 | 233 | 272 | 440 | 571 | 496 | 834 | 327 | 230 | 218 | 269 | 336 |
| 163 | 140 | 202 | 211 | 248 | 355 | 416 | 376 | 362 | 280 | 211 | 188 | 240 | 302 |
| 147 | 127 | 170 | 170 | 217 | 290 | 355 | 315 | 306 | 259 | 202 | 160 | 234 | 278 |
| 114 | 111 | 154 | 154 | 207 | 236 | 334 | 298 | 284 | 223 | 190 | 162 | 203 | 268 |
| 104 | 96 | 136 | 125 | 170 | — | 309 | 266 | 252 | 202 | 183 | 154 | — | 248 |
| 98 | — | 112 | 113 | 139 | — | 282 | 263 | 221 | 190 | — | — | — | 236 |
| — | — | — | 93 | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28, 0, P})$ dynamic metres | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 644 | 616 | 682 | 758 | 938 | 1281 | 1328 | 1358 | 1262 | 1148 | 909 | 720 | 900 | 957 |
| 1288 | 1232 | 1364 | 1516 | 1878 | 2564 | 2659 | 2718 | 2526 | 2297 | 1819 | 1440 | 1800 | 1915 |
| 1932 | 1847 | 2046 | 2274 | 2817 | 3848 | 3991 | 4081 | 3793 | 3442 | 2729 | 2159 | 2701 | 2873 |
| 2575 | 2456 | 2727 | 3032 | 3757 | 5134 | 5325 | 5441 | 5061 | 4583 | 3639 | 2878 | 3602 | 3832 |
| 3217 | 3060 | 3408 | 3790 | 4698 | 6417 | 6661 | 6797 | 6332 | 5725 | 4550 | 3596 | 4503 | 4792 |
| 3859 | 3645 | 4089 | 4548 | 5639 | 7695 | 7999 | 8155 | 7605 | 6868 | 5462 | 4314 | 5405 | 5752 |
| 5141 | 4523 | 5451 | 6056 | 7523 | 10247 | 10679 | 10869 | 10157 | 9148 | 7276 | 5674 | 7199 | 7672 |
| 6413 | 5105 | 6813 | 7554 | 9399 | 12807 | 13351 | 13573 | 12717 | 11346 | 9016 | 6698 | 8975 | 9596 |
| 9018 | 6425 | 9798 | 10749 | 13549 | 18952 | 19396 | 20013 | 18972 | 16306 | 12656 | 8398 | 12975 | 14416 |
| 10953 | 7640 | 12188 | 13294 | 17294 | 24632 | 24866 | 25948 | 24862 | 20786 | 15531 | 9833 | 16375 | 19071 |
| 14173 | 9900 | 16318 | 17804 | 25014 | 35392 | 35746 | 37338 | 36092 | 29136 | 20381 | 12453 | 22255 | 27541 |
| 16843 | 12010 | 19948 | 21584 | 32364 | 45682 | 46556 | 48458 | 47152 | 36676 | 24651 | 14983 | 27205 | 34921 |
| 21923 | 15690 | 26108 | 28184 | 44044 | 64162 | 68416 | 70318 | 69492 | 49756 | 31791 | 19903 | 35545 | 47661 |
| 26523 | 19210 | 31508 | 34224 | 52564 | 79882 | 89936 | 91158 | 91912 | 61056 | 37771 | 24583 | 42585 | 58921 |
| 30563 | 22590 | 36508 | 39504 | 59864 | 93722 | 109156 | 106518 | 114532 | 70996 | 43791 | 29163 | 48885 | 68501 |
| 39963 | 30590 | 47758 | 51304 | 75264 | 121022 | 145256 | 137518 | 164182 | 90796 | 57141 | 40263 | 63235 | 87751 |
| 48463 | 38090 | 58158 | 62404 | 88264 | 140872 | 169906 | 159318 | 194082 | 105946 | 68191 | 50413 | 75935 | 103701 |
| 56213 | 44790 | 67458 | 71904 | 99914 | 157022 | 189206 | 176618 | 210782 | 119446 | 78491 | 59113 | 87785 | 118201 |
| 62713 | 50740 | 75558 | 80004 | 110514 | 170172 | 206406 | 191918 | 225532 | 131496 | 88291 | 67163 | 98735 | 131851 |
| 68163 | 55890 | 82808 | 86954 | 119914 | — | 222506 | 206018 | 238932 | 142096 | 97591 | 75063 | — | 144751 |
| 73213 | — | 89008 | 92904 | 127664 | — | 237256 | 219218 | 250732 | 151896 | — | — | — | 156851 |
| — | — | — | 98054 | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — | — |

## Table III (*cont.*)

| Pressure decibars | Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 923 | 924 | 944 | 947 | 948 | 949 | 950 | 951 | 959 | 960 | 961 | 962 | 963 |
| | A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28, 0, P})$ | | | | | | | | | | | | |
| 0 | 1213 | 1327 | 966 | 1004 | 862 | 833 | 739 | 748 | 606 | 521 | 663 | 900 | 928 |
| 10 | 1215 | 1330 | 968 | 1006 | 863 | 825 | 729 | 748 | 597 | 521 | 673 | 902 | 930 |
| 20 | 1218 | 1333 | 969 | 1008 | 864 | 826 | 729 | 747 | 586 | 520 | 673 | 903 | 931 |
| 30 | 1219 | 1334 | 970 | 1009 | 864 | 827 | 730 | 747 | 586 | 520 | 674 | 904 | 932 |
| 40 | 1221 | 1328 | 971 | 1011 | 866 | 816 | 729 | 745 | 585 | 519 | 673 | 905 | 933 |
| 50 | 1223 | 1330 | 973 | 1012 | 876 | 817 | 729 | 745 | 585 | 519 | 673 | 906 | 935 |
| 60 | 1225 | 1332 | 974 | 1014 | 877 | 818 | 729 | 744 | 583 | 517 | 673 | 907 | 936 |
| 80 | 1229 | 1337 | 958 | 1016 | 880 | 811 | 730 | 743 | 582 | 516 | 664 | 909 | 939 |
| 100 | 1233 | 1323 | 961 | 1010 | 881 | 820 | 729 | 722 | 571 | 515 | 627 | 911 | 942 |
| 150 | 1242 | 1180 | 959 | 1026 | 860 | 823 | 729 | 776 | 463 | 407 | 566 | 917 | 949 |
| 200 | 1112 | 1142 | 944 | 1022 | 851 | 826 | 729 | 567 | 387 | 412 | 554 | 921 | 956 |
| 300 | 1095 | 1073 | 950 | 999 | 837 | 821 | 649 | 465 | 316 | 317 | 479 | 933 | 971 |
| 400 | 1073 | 1019 | 972 | 999 | 802 | 755 | 584 | 435 | 302 | 293 | 427 | 915 | 984 |
| 600 | 1065 | 1058 | 836 | 932 | 831 | 612 | 503 | 362 | 253 | 264 | 348 | 790 | 980 |
| 800 | 945 | 950 | 700 | 797 | 630 | 515 | 409 | 350 | 231 | 235 | 286 | 659 | 916 |
| 1000 | 837 | 820 | 599 | 683 | 505 | 458 | 335 | 301 | 227 | 220 | 276 | 560 | 796 |
| 1500 | 565 | 520 | 424 | 519 | 381 | 332 | 289 | 249 | 200 | 205 | 239 | 390 | 577 |
| 2000 | 386 | 376 | 323 | 403 | 294 | 299 | 266 | 228 | 166 | 181 | 208 | 325 | 411 |
| 2500 | 324 | 308 | 289 | 338 | 272 | 271 | 239 | 216 | 177 | 180 | 206 | 290 | 345 |
| 3000 | 269 | 273 | 274 | 299 | 246 | 238 | 233 | 212 | (180) | (180) | (206) | 262 | 329 |
| 3500 | 272 | 246 | 251 | 267 | 228 | 223 | 211 | — | — | — | — | 252 | 275 |
| 4000 | 281 | 243 | 223 | 239 | 224 | 217 | 225 | — | — | — | — | — | 286 |
| 4500 | — | — | 213 | 229 | 224 | 224 | 234 | — | — | — | — | — | — |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28, 0, P})$ dynamic metres | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1214 | 1329 | 967 | 1005 | 863 | 829 | 734 | 748 | 601 | 521 | 668 | 901 | 929 |
| 20 | 2430 | 2660 | 1935 | 2012 | 1726 | 1654 | 1463 | 1495 | 1193 | 1041 | 1341 | 1803 | 1859 |
| 30 | 3649 | 3994 | 2905 | 3020 | 2590 | 2481 | 2192 | 2242 | 1779 | 1561 | 2015 | 2706 | 2790 |
| 40 | 4869 | 5325 | 3875 | 4030 | 3455 | 3302 | 2922 | 2988 | 2364 | 2081 | 2688 | 3610 | 3722 |
| 50 | 6091 | 6654 | 4847 | 5042 | 4326 | 4119 | 3651 | 3733 | 2949 | 2600 | 3361 | 4515 | 4656 |
| 60 | 7315 | 7985 | 5820 | 6055 | 5203 | 4936 | 4380 | 4477 | 3533 | 3118 | 4034 | 5421 | 5592 |
| 80 | 9769 | 10653 | 7752 | 8085 | 6959 | 6566 | 5840 | 5965 | 4697 | 4150 | 5372 | 7237 | 7466 |
| 100 | 12231 | 13313 | 9672 | 10111 | 8721 | 8196 | 7298 | 7431 | 5851 | 5182 | 6662 | 9057 | 9348 |
| 150 | 18421 | 19573 | 14472 | 15201 | 13071 | 12306 | 10943 | 11176 | 8436 | 7487 | 9647 | 13627 | 14073 |
| 200 | 24306 | 25378 | 19227 | 20321 | 17351 | 16426 | 14588 | 14536 | 10561 | 9532 | 12447 | 18222 | 18838 |
| 300 | 35336 | 36448 | 28697 | 30421 | 25791 | 24666 | 21478 | 19696 | 14081 | 13182 | 17617 | 27492 | 28468 |
| 400 | 46176 | 46908 | 38307 | 40411 | 33981 | 32546 | 27638 | 24196 | 17171 | 16232 | 22147 | 36732 | 38248 |
| 600 | 67556 | 67668 | 56387 | 59711 | 50321 | 46206 | 38518 | 32156 | 22711 | 21792 | 29907 | 53772 | 57888 |
| 800 | 87656 | 87748 | 71747 | 77011 | 64921 | 57486 | 47638 | 39276 | 27551 | 26792 | 36247 | 68272 | 76848 |
| 1000 | 105476 | 105448 | 84727 | 91811 | 76281 | 67206 | 55078 | 45796 | 32131 | 31332 | 41867 | 80452 | 93968 |
| 1500 | 140526 | 138948 | 110327 | 121861 | 98431 | 86956 | 70678 | 59546 | 42831 | 41982 | 54717 | 104202 | 128268 |
| 2000 | 164326 | 161348 | 128977 | 144911 | 112781 | 102706 | 84528 | 71496 | 51981 | 51632 | 65917 | 122102 | 152968 |
| 2500 | 182076 | 178448 | 144277 | 163411 | 126931 | 116956 | 97178 | 82596 | 60531 | 60632 | 76267 | 137452 | 171868 |
| 3000 | 196876 | 192948 | 158377 | 179361 | 139881 | 129656 | 108978 | 93296 | (69481) | (69632) | (86567) | 151252 | 188718 |
| 3500 | 210426 | 205948 | 171477 | 193511 | 151731 | 141206 | 120078 | — | — | — | — | 164102 | 203818 |
| 4000 | 224226 | 218148 | 183327 | 206161 | 163031 | 152206 | 130978 | — | — | — | — | — | 217868 |
| 4500 | — | — | 194227 | 217861 | 174231 | 163256 | 142478 | — | — | — | — | — | — |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |

Table III (*cont.*)

| Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 965 | 966 | 967 | 969 | 970 | 972 | 974 | 975 | 976 | 977 | 978 | 983 | 984 | 985 |
| A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28, 0, P})$ | | | | | | | | | | | | | |
| 1004 | 1299 | 1555 | 1213 | 862 | 710 | 692 | 673 | 748 | 824 | 909 | 1156 | 890 | 881 |
| 1006 | 1301 | 1557 | 1215 | 863 | 710 | 692 | 673 | 749 | 825 | 911 | 1158 | 892 | 883 |
| 1008 | 1303 | 1559 | 1217 | 864 | 711 | 692 | 673 | 750 | 826 | 912 | 1169 | 893 | 893 |
| 1009 | 1304 | 1561 | 1218 | 865 | 711 | 690 | 674 | 750 | 827 | 912 | 1170 | 895 | 894 |
| 1011 | 1306 | 1563 | 1220 | 865 | 711 | 690 | 673 | 750 | 828 | 914 | 1171 | 895 | 885 |
| 1012 | 1308 | 1565 | 1222 | 866 | 711 | 690 | 673 | 751 | 829 | 915 | 1173 | 896 | 887 |
| 1014 | 1310 | 1566 | 1214 | 867 | 712 | 690 | 673 | 752 | 830 | 916 | 1174 | 897 | 888 |
| 1016 | 1276 | 1561 | 1208 | 868 | 713 | 688 | 674 | 744 | 832 | 917 | 1167 | 899 | 890 |
| 992 | 1250 | 1546 | 1164 | 869 | 713 | 687 | 673 | 744 | 824 | 892 | 1024 | 901 | 892 |
| 989 | 1193 | 1336 | 1123 | 874 | 715 | 685 | 673 | 746 | 830 | 879 | 973 | 888 | 898 |
| 977 | 1151 | 1136 | 1063 | 875 | 715 | 616 | 673 | 748 | 825 | 883 | 912 | 892 | 893 |
| 983 | 1022 | 1006 | 990 | 816 | 688 | 539 | 605 | 741 | 805 | 894 | 895 | 894 | 886 |
| 978 | 1006 | 976 | 986 | 772 | 633 | 462 | 550 | 670 | 813 | 897 | 896 | 895 | 888 |
| 992 | 1012 | 994 | 989 | 650 | 584 | 378 | 503 | 614 | 807 | 876 | 885 | 894 | 906 |
| 948 | 979 | 914 | 940 | 556 | 444 | 360 | 430 | 528 | 741 | 840 | 854 | 855 | 891 |
| 850 | 900 | 815 | 840 | 483 | 374 | 322 | 374 | 453 | 702 | 744 | 573 | 734 | 734 |
| 560 | 553 | 560 | 563 | 362 | 307 | 260 | 287 | 342 | 462 | 516 | 491 | 513 | 520 |
| 427 | 420 | 384 | 417 | 294 | 272 | 236 | 265 | 286 | 374 | 376 | 391 | 393 | 400 |
| 376 | 354 | 341 | 375 | 267 | 236 | 223 | 258 | 269 | 296 | 348 | 372 | 373 | 330 |
| 352 | 346 | 340 | 352 | 248 | 222 | 202 | 230 | 255 | 276 | 311 | 323 | 328 | 302 |
| 320 | 342 | 332 | 345 | — | 196 | 186 | 219 | 236 | 262 | 263 | 269 | — | 259 |
| 300 | 325 | 328 | — | — | 175 | 166 | 188 | 196 | 206 | 213 | 216 | — | — |
| 295 | 290 | — | — | — | 156 | 171 | 174 | 183 | 173 | 196 | — | — | — |
| — | — | — | — | — | 156 | 165 | — | 184 | — | — | — | — | — |
| B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28, 0, P})$ dynamic metres | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1005 | 1300 | 1556 | 1214 | 863 | 710 | 692 | 673 | 748 | 824 | 910 | 1157 | 891 | 882 |
| 2012 | 2602 | 3114 | 2430 | 1726 | 1420 | 1384 | 1346 | 1497 | 1650 | 1821 | 2320 | 1784 | 1770 |
| 3020 | 3905 | 4674 | 3647 | 2591 | 2131 | 2075 | 2020 | 2247 | 2476 | 2733 | 3490 | 2678 | 2664 |
| 4030 | 5210 | 6236 | 4866 | 3456 | 2842 | 2765 | 2693 | 2997 | 3304 | 3646 | 4660 | 3573 | 3553 |
| 5042 | 6517 | 7800 | 6087 | 4321 | 3553 | 3455 | 3366 | 3748 | 4132 | 4560 | 5832 | 4469 | 4439 |
| 6055 | 7826 | 9365 | 7305 | 5188 | 4265 | 4145 | 4039 | 4500 | 4962 | 5475 | 7005 | 5365 | 5327 |
| 8085 | 10412 | 12493 | 9727 | 6922 | 5691 | 5523 | 5387 | 5996 | 6624 | 7307 | 9247 | 7161 | 7105 |
| 10093 | 12938 | 15599 | 12099 | 8660 | 7117 | 6899 | 6733 | 7484 | 8280 | 9117 | 11437 | 8961 | 8887 |
| 15043 | 19048 | 22804 | 17819 | 13015 | 10687 | 10329 | 10098 | 11209 | 12415 | 13542 | 16432 | 13431 | 13362 |
| 19958 | 24908 | 28984 | 23284 | 17390 | 14262 | 13579 | 13463 | 14944 | 16550 | 17947 | 21142 | 17881 | 17837 |
| 29758 | 35778 | 39694 | 33544 | 25850 | 21272 | 19359 | 19853 | 22394 | 24700 | 26837 | 30182 | 26811 | 26737 |
| 39558 | 45918 | 49604 | 43424 | 33790 | 27882 | 24359 | 25633 | 29444 | 32790 | 35787 | 39132 | 35761 | 35607 |
| 59258 | 66098 | 69304 | 63184 | 48010 | 40042 | 32759 | 36153 | 42284 | 48970 | 53507 | 56952 | 53641 | 53547 |
| 78658 | 85998 | 88384 | 82464 | 60070 | 50322 | 40139 | 45493 | 53704 | 64450 | 70667 | 74332 | 71121 | 71507 |
| 96638 | 104798 | 105684 | 100264 | 70450 | 58502 | 46959 | 53533 | 63524 | 78890 | 86507 | 88612 | 87021 | 87767 |
| 131888 | 141098 | 140034 | 135364 | 91600 | 75552 | 61509 | 70033 | 83374 | 107990 | 118007 | 115212 | 118171 | 119117 |
| 156538 | 165448 | 163634 | 159864 | 108000 | 90002 | 73909 | 83833 | 99074 | 128890 | 140307 | 137262 | 140821 | 142117 |
| 176588 | 184798 | 181784 | 179664 | 122000 | 102702 | 85409 | 96883 | 112974 | 145640 | 158407 | 156362 | 159971 | 160367 |
| 194788 | 202298 | 198784 | 197864 | 134900 | 114152 | 96009 | 109083 | 126074 | 159940 | 174907 | 173712 | 177521 | 176167 |
| 211588 | 219498 | 215584 | 215264 | — | 124602 | 105709 | 120333 | 138324 | 173390 | 189257 | 188512 | — | 190217 |
| 227088 | 236148 | 232084 | — | — | 133852 | 114509 | 130483 | 149124 | 185090 | 201157 | 200612 | — | — |
| 241988 | 251548 | — | — | — | 142152 | 122959 | 139533 | 158574 | 194540 | 211357 | — | — | — |
| — | — | — | — | — | 149952 | 131359 | — | 167774 | — | — | — | — | — |

## Table III (*cont.*)

| Pressure decibars | Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 986 | 988 | 990 | 992 | 994 | 1049 | 1050 | 1053 | 1054 | 1055 | 1138 | 1142 | 1146 |
| | A. Anomalies of Specific Volume $10^6 (\alpha - \alpha_{28, 0, P})$ | | | | | | | | | | | | |
| 0 | 852 | 767 | 758 | 701 | 606 | 606 | 616 | 833 | 890 | 985 | 654 | 919 | 464 |
| 10 | 854 | 768 | 759 | 701 | 606 | 606 | 606 | 834 | 891 | 986 | 654 | 919 | 464 |
| 20 | 855 | 769 | 760 | 700 | 605 | 597 | 606 | 834 | 892 | 978 | 654 | 919 | 464 |
| 30 | 857 | 770 | 759 | 700 | 605 | 597 | 606 | 826 | 892 | 979 | 655 | 815 | 464 |
| 40 | 857 | 770 | 760 | 698 | 604 | 596 | 606 | 815 | 892 | 981 | 654 | 786 | 464 |
| 50 | 858 | 772 | 761 | 698 | 604 | 585 | 606 | 816 | 893 | 982 | 644 | 739 | 464 |
| 60 | 859 | 773 | 762 | 697 | 602 | 576 | 576 | 817 | 885 | 981 | 644 | 729 | 396 |
| 80 | 861 | 774 | 763 | 696 | 601 | 575 | 499 | 760 | 809 | 898 | 539 | 692 | 213 |
| 100 | 863 | 775 | 764 | 694 | 590 | 536 | 440 | 684 | 673 | 812 | 452 | 703 | 211 |
| 150 | 869 | 780 | 767 | 618 | 504 | 525 | 303 | 598 | 607 | 727 | 366 | 431 | 140 |
| 200 | 873 | 784 | 752 | 544 | 442 | 273 | 240 | 544 | 562 | 708 | 264 | 339 | 162 |
| 300 | 865 | 752 | 726 | 454 | 397 | 183 | 206 | 456 | 455 | 682 | 230 | 249 | 153 |
| 400 | 864 | 746 | 707 | 422 | 345 | 176 | 204 | 388 | 400 | 686 | 177 | 217 | 154 |
| 600 | 845 | 739 | 643 | 365 | 303 | 172 | 167 | 300 | 312 | 524 | 171 | 200 | 154 |
| 800 | 778 | 612 | 540 | 321 | 272 | 143 | 168 | 266 | 302 | 412 | 173 | 170 | 146 |
| 1000 | 691 | 548 | 463 | 291 | 250 | 142 | 155 | 256 | 253 | 355 | 163 | 172 | 144 |
| 1500 | 480 | 442 | 407 | 256 | 221 | 137 | 153 | 222 | 232 | 291 | 149 | 160 | 127 |
| 2000 | 382 | 354 | 336 | 218 | 204 | 120 | 135 | 203 | 207 | 269 | 133 | 137 | 107 |
| 2500 | 322 | 294 | 276 | 209 | 197 | 111 | 125 | 180 | 185 | 233 | 115 | 125 | 96 |
| 3000 | 279 | 251 | 230 | 211 | 177 | 109 | 115 | 150 | 157 | 193 | 107 | 104 | 80 |
| 3500 | — | 225 | 201 | — | 169 | — | 83 | — | 136 | 168 | 103 | 76 | 64 |
| 4000 | — | 191 | 163 | — | 168 | — | — | — | 120 | 143 | — | 75 | 50 |
| 4500 | — | 169 | 168 | — | — | — | — | — | 121 | 137 | — | — | 45 |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | B. Anomalies of Depth of Isobaric Surfaces $10^5 (D - D_{28, 0, P})$ dynamic metres | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 853 | 767 | 758 | 701 | 606 | 606 | 611 | 833 | 890 | 985 | 654 | 919 | 464 |
| 20 | 1708 | 1536 | 1517 | 1402 | 1212 | 1207 | 1217 | 1667 | 1781 | 1967 | 1308 | 1838 | 928 |
| 30 | 2564 | 2305 | 2276 | 2102 | 1817 | 1804 | 1823 | 2497 | 2673 | 2946 | 1963 | 2705 | 1392 |
| 40 | 3421 | 3075 | 3036 | 2801 | 2421 | 2401 | 2429 | 3317 | 3565 | 3926 | 2617 | 3505 | 1856 |
| 50 | 4278 | 3846 | 3797 | 3499 | 3025 | 2991 | 3035 | 4133 | 4458 | 4907 | 3266 | 4273 | 2320 |
| 60 | 5137 | 4618 | 4559 | 4196 | 3628 | 3572 | 3626 | 4949 | 5347 | 5889 | 3910 | 5007 | 2750 |
| 80 | 6857 | 6164 | 6085 | 5588 | 4832 | 4722 | 4702 | 6527 | 7041 | 7769 | 5092 | 6427 | 3358 |
| 100 | 8581 | 7712 | 7613 | 6978 | 6022 | 5834 | 5640 | 7971 | 8523 | 9479 | 6084 | 7823 | 3782 |
| 150 | 12911 | 11602 | 11438 | 10258 | 8757 | 8484 | 7500 | 11176 | 11723 | 13324 | 8129 | 10658 | 4662 |
| 200 | 17266 | 15512 | 15238 | 13163 | 11122 | 10479 | 8855 | 14031 | 14643 | 16914 | 9704 | 12583 | 5417 |
| 300 | 25956 | 23192 | 22628 | 17653 | 15322 | 12759 | 11085 | 19031 | 19733 | 23864 | 12174 | 15523 | 6987 |
| 400 | 34596 | 30682 | 29788 | 22033 | 19032 | 14559 | 13135 | 23251 | 24003 | 30704 | 14214 | 17853 | 8527 |
| 600 | 51696 | 45522 | 43288 | 29893 | 25512 | 18039 | 16835 | 30131 | 31123 | 42804 | 17694 | 22013 | 11607 |
| 800 | 67916 | 59042 | 55108 | 36753 | 31252 | 21179 | 20195 | 35791 | 37263 | 52164 | 21134 | 25713 | 14607 |
| 1000 | 82616 | 70642 | 65148 | 42873 | 36472 | 24039 | 23415 | 41011 | 42823 | 59824 | 24494 | 29133 | 17507 |
| 1500 | 111866 | 95392 | 86898 | 56523 | 48272 | 30989 | 31115 | 52961 | 54923 | 75974 | 32294 | 37433 | 24307 |
| 2000 | 133416 | 115292 | 105448 | 68373 | 58872 | 37439 | 38315 | 63611 | 65923 | 89974 | 39344 | 44883 | 30157 |
| 2500 | 151016 | 131492 | 120748 | 79073 | 68922 | 43189 | 44815 | 73161 | 75723 | 102524 | 45544 | 51433 | 35207 |
| 3000 | 166066 | 145142 | 133398 | 89573 | 78272 | 48689 | 50815 | 81411 | 84273 | 113174 | 51094 | 57133 | 39607 |
| 3500 | — | 157042 | 144198 | — | 86922 | — | 55765 | — | 91573 | 122174 | 56344 | 61633 | 43207 |
| 4000 | — | 167442 | 153298 | — | 95372 | — | — | — | 97973 | 129974 | — | 65433 | 46057 |
| 4500 | — | 176442 | 161548 | — | — | — | — | — | 104023 | 136974 | — | — | 48407 |
| 5000 | — | — | — | — | — | — | — | — | — | — | — | — | — |

## Table III (*cont.*)

| Stations | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1148 | 1150 | 1152 | 1154 | 1156 | 1158 | 1162 | 1165 | WS 365 | WS 379 | WS 400 | WS 401 | WS 402 | WS 403 | WS 404 |
| A. Anomalies of Specfic Volume $10^6 (\alpha-\alpha_{28,0,P})$ | | | | | | | | | | | | | | |
| 635 | 606 | 388 | 474 | 710 | 833 | 1185 | 1849 | 810 | 740 | 1030 | 1030 | 1050 | 1080 | 1130 |
| 635 | 606 | 388 | 474 | 710 | 833 | 1187 | 1853 | 820 | 750 | 1060 | 1030 | 1050 | 1080 | 1130 |
| 635 | 597 | 388 | 473 | 710 | 833 | 1188 | 1855 | 810 | 670 | 1060 | 1020 | 1060 | 1080 | 1130 |
| 635 | 597 | 387 | 463 | 663 | 834 | 1189 | 1858 | 810 | 630 | 1040 | 1020 | 900 | 1070 | 1130 |
| 624 | 586 | 378 | 425 | 624 | 824 | 1191 | 1861 | 810 | 620 | 960 | 990 | 870 | 1030 | 980 |
| 529 | 568 | 368 | 416 | 367 | 462 | 1192 | 1864 | 800 | 610 | 840 | 860 | 830 | 850 | 910 |
| 356 | 321 | 368 | 405 | 338 | 422 | 1193 | 1867 | 790 | 580 | 820 | 780 | 720 | 780 | 860 |
| 336 | 181 | 358 | 376 | 291 | 412 | 1196 | 1873 | 770 | 460 | 710 | 760 | 710 | 730 | 750 |
| 324 | 182 | 318 | 336 | 218 | 392 | 1149 | 1870 | 720 | 390 | 620 | 710 | 670 | 640 | 710 |
| 225 | 164 | 223 | 209 | 193 | 195 | 906 | 1877 | 660 | 330 | 450 | 530 | 630 | 590 | 690 |
| 163 | 155 | 191 | 258 | 195 | 153 | 858 | 1359 | 610 | 300 | 380 | 470 | 580 | 570 | 660 |
| 145 | 155 | 176 | 165 | 196 | 154 | 800 | 1044 | 530 | 270 | 340 | 390 | 520 | 500 | 600 |
| 145 | 155 | 180 | 177 | 190 | 154 | 745 | 890 | 460 | 280 | 310 | 340 | 450 | 460 | 510 |
| 146 | 159 | 173 | 172 | 183 | 144 | 681 | 720 | 390 | 240 | 280 | 310 | 400 | 370 | 430 |
| 148 | 160 | 174 | 153 | 174 | 136 | 584 | 620 | 380 | 220 | 250 | 310 | 350 | 350 | 370 |
| 137 | 150 | 162 | 150 | 164 | 143 | 500 | 535 | 310 | 210 | 230 | 280 | 350 | 310 | 340 |
| 122 | 137 | 136 | 136 | 146 | 125 | 373 | 385 | 240 | 210 | 220 | 250 | 280 | 270 | 300 |
| 112 | 128 | 117 | 118 | 120 | 106 | 318 | 320 | 200 | 180 | 190 | 240 | 280 | 260 | 280 |
| 112 | 107 | 100 | 111 | 108 | 96 | 294 | 305 | — | — | — | — | — | — | — |
| 92 | 99 | 101 | 105 | 101 | 87 | 264 | 312 | 150 | 150 | 170 | 200 | 230 | 220 | 250 |
| 84 | 80 | 97 | — | 95 | 78 | 229 | 286 | — | — | — | — | — | — | — |
| 73 | — | — | — | 84 | 67 | 198 | 246 | — | — | — | — | — | — | — |
| 61 | — | — | — | 79 | 59 | — | 223 | — | — | — | — | — | — | — |
| 54 | — | — | — | — | 58 | — | — | — | — | — | — | — | — | — |
| B. Anomalies of Depth of Isobaric Surfaces $10^5 (D-D_{28,0,P})$ dynamic metres | | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 635 | 606 | 388 | 474 | 710 | 833 | 1186 | 1851 | 815 | 745 | 1045 | 1030 | 1050 | 1080 | 1130 |
| 1270 | 1207 | 776 | 947 | 1420 | 1666 | 2373 | 3705 | 1630 | 1455 | 2105 | 2055 | 2105 | 2160 | 2260 |
| 1905 | 1804 | 1163 | 1415 | 2106 | 2500 | 3562 | 5561 | 2440 | 2105 | 3155 | 3075 | 3085 | 3235 | 3390 |
| 2535 | 2396 | 1546 | 1859 | 2750 | 3329 | 4752 | 7421 | 3250 | 2730 | 4155 | 4080 | 3970 | 4285 | 4445 |
| 3111 | 2973 | 1919 | 2280 | 3245 | 3972 | 5943 | 9283 | 4055 | 3345 | 5055 | 5005 | 4805 | 5225 | 5390 |
| 3554 | 3417 | 2287 | 2690 | 3598 | 4414 | 7136 | 11149 | 4850 | 3940 | 5885 | 5825 | 5595 | 6040 | 6275 |
| 4246 | 3919 | 3013 | 3472 | 4226 | 5248 | 9524 | 14889 | 6410 | 4980 | 7415 | 7365 | 7025 | 7550 | 7885 |
| 4906 | 4283 | 3689 | 4184 | 4736 | 6052 | 11870 | 18631 | 7900 | 5830 | 8745 | 8835 | 8405 | 8920 | 9345 |
| 6276 | 5148 | 5039 | 5549 | 5761 | 7517 | 17005 | 28001 | 11350 | 7630 | 11420 | 11835 | 11655 | 11995 | 12845 |
| 7246 | 5943 | 6074 | 6714 | 6731 | 8387 | 21415 | 36091 | 14525 | 9205 | 13495 | 14335 | 14680 | 14895 | 16220 |
| 8786 | 7493 | 7914 | 8834 | 8691 | 9917 | 29705 | 48101 | 20225 | 12055 | 17095 | 18635 | 20180 | 20245 | 22520 |
| 10236 | 9043 | 9694 | 10544 | 10621 | 11457 | 37435 | 57771 | 25075 | 14805 | 20345 | 22290 | 25030 | 25050 | 28070 |
| 13156 | 12183 | 13214 | 14024 | 14361 | 14437 | 51695 | 73871 | 33375 | 20005 | 26250 | 28785 | 33530 | 33345 | 37470 |
| 16096 | 15383 | 16694 | 17284 | 17921 | 17237 | 64355 | 87271 | 41075 | 24605 | 31545 | 35985 | 41030 | 40545 | 45470 |
| 18936 | 18483 | 20054 | 20304 | 21301 | 20037 | 75195 | 98831 | 47975 | 28905 | 36345 | 41885 | 48030 | 47145 | 52570 |
| 25436 | 25633 | 27504 | 27454 | 29051 | 26737 | 97045 | 121831 | 61725 | 39405 | 47595 | 55135 | 63780 | 61650 | 68570 |
| 31286 | 32283 | 33804 | 33804 | 35701 | 32537 | 114295 | 139431 | 72725 | 49155 | 57845 | 67385 | 77780 | 74900 | 83070 |
| 36886 | 38183 | 39254 | 39504 | 41401 | 37587 | 129595 | 155081 | — | — | — | — | — | — | — |
| 41736 | 43333 | 44254 | 44904 | 46601 | 42137 | 143545 | 170481 | 90225 | 65655 | 75845 | 89385 | 103280 | 101295 | 109570 |
| 46136 | 47833 | 49204 | — | 51501 | 46287 | 155895 | 185431 | — | — | — | — | — | — | — |
| 50036 | — | — | — | 56001 | 49887 | 166545 | 198731 | — | — | — | — | — | — | — |
| 53386 | — | — | — | 60051 | 53037 | — | 210431 | — | — | — | — | — | — | — |
| 56286 | — | — | — | — | 55937 | — | — | — | — | — | — | — | — | — |

Table IV. *The dynamic depths of the* 0–5000 *decibar isobaric surfaces in a sea of uniform temperature* 0° C. *and density* ($\sigma_t$) 28·00

| Pressure decibars | Dynamic depth $D_{28,\,0,\,P}$ dyn. metres | Pressure decibars | Dynamic depth $D_{28,\,0,\,P}$ dyn. metres |
|---|---|---|---|
| 0 | 0 | 400 | 388·74370 |
| 10 | 9·72735 | 600 | 582·84670 |
| 20 | 19·45425 | 800 | 776·77170 |
| 30 | 29·18075 | 1000 | 970·51970 |
| 40 | 38·90680 | 1500 | 1454·12720 |
| 50 | 48·63235 | 2000 | 1936·65970 |
| 60 | 58·35745 | 2500 | 2418·63220 |
| 80 | 77·80635 | 3000 | 2899·05970 |
| 100 | 97·25345 | 3500 | 3378·45970 |
| 150 | 145·86320 | 4000 | 3856·84720 |
| 200 | 194·46170 | 4500 | 4334·23970 |
| 300 | 291·62520 | 5000 | 4810·65220 |

[*Discovery Reports. Vol. XV, pp.* 153–222, *Plates XLV–LVI, March* 1936.]

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

# NEW SPECIES OF MARINE MOLLUSCA FROM NEW ZEALAND

By

A. W. B. POWELL,
Auckland Museum.

# CONTENTS

Introductory Note . . . . . . . . . . . . . . . . . . *page* 155

The Molluscan Fauna of Northern New Zealand . . . . . . . . 156

Material Examined . . . . . . . . . . . . . . . . . 157

List of Mollusca Collected . . . . . . . . . . . . . . 158

Systematic Account . . . . . . . . . . . . . . . . . 163
  Pelecypoda . . . . . . . . . . . . . . . . . . 163
  Gasteropoda . . . . . . . . . . . . . . . . . . 175
  Amphineura . . . . . . . . . . . . . . . . . . 219

Plates XLV–LVI . . . . . . . . . . . . . *following page* 222

# NEW SPECIES OF MARINE MOLLUSCA FROM NEW ZEALAND

By A. W. B. Powell
Auckland Museum

(Plates XLV–LVI)

## INTRODUCTORY NOTE

The material described in this paper was dredged by the R.R.S. 'Discovery II', during a visit to New Zealand in August 1932.

As the usual routine of plankton stations was not required in New Zealand coastal waters, the opportunity was taken to repeat some of the bottom stations made off the extreme north of New Zealand by the Terra Nova Expedition of 1910.

The writer gratefully acknowledges the invitation given him by the late Commander W. M. Carey and Mr Dilwyn John to join the ship on the coastal cruise from Auckland to Wellington, via the Three Kings Islands and the west coast, and also their willingness to undertake an extension of the work by dredging in several additional localities suggested by the writer. The writer is also indebted to the Discovery Committee for granting him the privilege of reporting on the molluscan material dredged on this occasion.

For assistance rendered in the tedious work of sorting microscopic specimens from the dredgings, the writer records his thanks to Mrs Powell, Mr W. K. Hounsell and Mr A. G. Stevenson.

The holotypes of all the species herein described, and in most cases a representative series of paratypes of each species, are to be deposited in the British Museum of Natural History, London. Many of the new species occur in abundance, and specimens of these will be retained for the Auckland Museum collection.

In spite of the fact that dredging was done in the vicinity of the Three Kings Islands by the 'Terra Nova' in 1910, the collections of the 'Discovery II' contain a large number of new species. Included are six new genera and 128 new species, and thirteen genera not previously known from New Zealand waters. The large percentage of new species obtained from the Discovery II dredgings is due to the efficiency of the conical dredge, as it brings up a fair sample and does not allow of any appreciable sieving of the fine materials on the way to the surface.

# THE MOLLUSCAN FAUNA OF NORTHERN NEW ZEALAND

A noteworthy feature of the fauna from these islands and the far north of the North Island generally, is the number of genera and species typical of Australian seas. To the known list of these occurrences may now be added the following genera: *Cratis*, *Dimya*, *Epicodakia*, *Borniola*, *Zeidora*, *Starkeyna*, *Coenaculum* and *Pedicularia*.

In 1925, Finlay (*Verbeek Mem. Birthday Vol.*, p. 168) published a manuscript scheme of Iredale's, dividing the New Zealand faunal subregion into the following five provinces:

Kermadec Province = Kermadec Islands.
Cookian Province = North Island of New Zealand.
Forsterian Province = South and Stewart Islands.
Moriorian Province = Chatham Islands.
Rossian Province = Subantarctic Islands, including Macquarie Island.

In a later paper 1926 (*Trans. N.Z. Inst.*, LVII, p. 328) Finlay added the proviso that "the Cookian and Forsterian provinces as defined may not be natural and may be subdivisible later—in which case the present names are to be retained for the southern portions of each island. Cook Strait has been adopted as a temporary dividing line purely for present convenience; many characteristic regional forms are known to range across it. The quite recent development of Cook Strait as a geomorphic feature may account for this....North of the Hauraki Gulf there may possibly be a different provincial region (the Cape Maria van Diemen fauna seems notably distinct)."

Finlay's suggested new province for the Cape Maria van Diemen area is undoubtedly a good one, and since the material herein described contains additional evidence of the distinctive character of its fauna I have no hesitation in accepting this area as a distinctive province and provide for it the name Aupourian. It includes the northernmost portion of Finlay's Cookian Province and in extent covers the Three Kings Islands and all that part of the North Auckland Peninsula above Ahipara on the west and Whangaroa on the east coast. It also seems to me that the Cookian should comprise all the rest of the North Island and the northern part of the South Island down to Westport on the west coast and Bank's Peninsula on the east. Below this on both coasts extensive shingle beaches sparse in marine fauna form a good boundary, a "no-man's-land" as it were, between the Cookian and the rock-bound Otago area plus Stewart Island, which is another quite compact and well-defined faunal province (Finlay's Forsterian, in part).

Among the distinctive marine molluscs of the Aupourian are the following: *Gomphina maorum*, Smith; *Zegalerus tumens*, Finlay; *Venericardia reinga*, Powell; *Herpetopoma mariae*, Finlay; *Notocochlis migratoria*, Powell; *Cosa laevicostata*, Powell; *Galfridus virginalis*, Suter; *Marginella vailei*, Powell; and a large number of species described herein, particularly the new species of *Cratis*, *Pedicularia*, *Dimya*, *Epicodakia*, *Borniola*, *Zeidora*, *Starkeyna* and *Coenaculum*.

Also the land molluscan fauna of this proposed new province has the following restricted species: *Placostylus bollonsi*, Suter; *Placostylus hongii ambagiosus*, Suter; *Rhytida duplicata*, Suter; *Serpho matthewsi*, Suter; and *Succinea archeyi*, Powell.

The name of the province is based upon the name of a northern Maori tribe, the Aupouri, and is particularly appropriate, as these people originally dwelt on the northernmost mainland until they were defeated in battle by the Ngapuhi people and forced to flee to the Three Kings Islands.

## MATERIAL EXAMINED

The material examined consisted of bottom samples from the conical dredge and residue from the otter trawl. A list of the stations from which molluscan material was obtained is as follows:

St. 929. 16. viii. 1932. 34° 21·0′ S, 172° 48·0′ E, off Spirit's Bay, northern New Zealand, 59 m. Conical dredge. Bottom fine sand and coarse shell. Temperature 14·79° C.; *p*H (at 15° C.) 8·26; salinity 35·41 $^{\circ}/_{\circ\circ}$, time 1114–1115.

St. 929. 16. viii. 1932. 34° 21·0′ S, 172° 48·0′ E to 34° 22·2′ S, 172° 49·8′ E, off Spirit's Bay, northern New Zealand, 59–55 m. Otter trawl. Time 1150–1250.

St. 930. 16. viii. 1932. North Cape Lighthouse, 035° dist. 1·8 miles (off Waikuku Beach), 29 m. Conical dredge. Bottom fine sand and shell. Temperature 14·50° C.; time 1640–1730.

St. 931. 17. viii. 1932. 34° 14·8′ S, 172° 30′ E, between Spirit's Bay and Three Kings Islands, 95 m. Conical dredge. Bottom hard, comminuted shells and bryozoans. Temperature 14·63° C.; *p*H (at 15° C.) 8·22; salinity 35·39 $^{\circ}/_{\circ\circ}$; time 0720–0800.

St. 932. 17. viii. 1932. 34° 13·0′ S, 172° 15·9′ E, off Three Kings Islands, 185 m. Conical dredge. Bottom hard, comminuted shells and bryozoans. Temperature 14·62° C.; *p*H (at 15° C.) 8·22; salinity 35·37 $^{\circ}/_{\circ\circ}$; time 1007.

St. 933. 17. viii. 1932. 34° 13·3′ S, 172° 12·0′ E, off Three Kings Islands, 260 m. Conical dredge. Bottom hard, comminuted shells and bryozoans. Temperature 14·60° C.; *p*H (at 15° C.) 8·22; salinity 35·37 $^{\circ}/_{\circ\circ}$; time 1125.

St. 934. 17. viii. 1932. 34° 11·6′ S, 172° 10·9′ E, off Three Kings Islands, 92 m. Conical dredge. Bottom hard, comminuted shells and bryozoans. Temperature 14·35° C.; *p*H (at 15° C) 8·22; salinity 35·35 $^{\circ}/_{\circ\circ}$; time 1205.

# LIST OF MOLLUSCA COLLECTED

(c.) after the name of a species indicates that more than ten examples were obtained, and (v.c.) more than fifty examples. Of the unmarked species less than ten examples were collected. No species is based upon a unique specimen.

## Pelecypoda

### Family NUCULIDAE

***Pronucula maoria***, n.sp. St. 933.

### Family NUCULANIDAE

***Nuculana (Jupiteria) manawatawhia***, n.sp. St. 933.

*Ledella finlayi*, Powell, 1935. St. 933.

### Family ARCIDAE

*Acar sandersonae*, Powell, 1933. St. 934.

*Barbatia novaezelandiae*, Smith, 1915. St. 934.

*Glycymeris laticostata* (Quoy and Gaimard, 1835). St. 929.

### Family LIMOPSIDAE

***Aupouria parvula**, n.gen. et sp. Sts. 933, 934. (c.)

### Family PHILOBRYIDAE

*Cosa filholi* (Bernard, 1897). St. 933. (v.c.)

*Cosa serratocostata*, Powell, 1933. St. 934. (c.)

***Cosa serratocostata dispar***, n.subsp. St. 933. (c.)

***Cratis retiaria**, n.sp. St. 933. (c.)

***Cratis delicatula***, n.sp. St. 933. (c.)

### Family MYTILIDAE

*Dacrydium radians*, Suter, 1908. St. 930.

*Dacrydium pelseneeri*, Hedley, 1906. St. 933.

### Family PECTINIDAE

*Pallium* (*Mesopeplum*) *convexus* (Quoy and Gaimard, 1835). Sts. 929, 931.

*Chlamys consociata*, Smith, 1915. St. 934.

***Cyclopecten (Cyclochlamys) aupouria***, n.sp. St. 933.

*Cyclopecten* (*Cyclochlamys*) *secundus*, Finlay, 1926. St. 933.

### Family DIMYIDAE

***Dimya maoria**, n.sp. St. 933.

### Family LIMIDAE

*Lima sydneyensis*, Hedley, 1904. St. 933.

***Limatula aupouria***, n.sp. St. 933.

*Mantellum murrayi* (Smith, 1891). St. 933.

### Family CRASATELLITIDAE

*Talabrica bellula* (A. Adams, 1854). St. 929.

***Cuna aupouria***, n.sp. St. 933. (c.)

***Cuna waikukuensis***, n.sp. St. 930. (c.)

***Cuna manawatawhia***, n.sp. St. 934. (c.)

***Cuna gibbosa***, n.sp. St. 933.

### Family CARDITIDAE

*Venericardia reinga*, Powell, 1933. Sts. 929, 934.

*Pleuromeris* cf. *marshalli*, Marwick, 1924. St. 933.

***Pleuromeris latiuscula***, n.sp. St. 930. (v.c.)

***Pleuromeris latiuscula benthicola***, n.subsp. St. 933. (v.c.)

---

* Denotes genera not previously recorded from New Zealand waters.

### Family CONDYLOCARDIIDAE

*Condylocardia concentrica*, Bernard, 1897. St. 933.

*Benthocardiella* aff. *pusilla*, Powell, 1930. Sts. 933, 931.

*Benthocardiella orbicula*, Powell, 1930. St. 933.

*Benthocardiella hamatadens*, Powell, 1930. Sts. 933, 934. (c.)

### Family LUCINIDAE

*Gonimyrtea concinna* (Hutton, 1885). St. 931.

****Epicodakia neozelanica***, n.sp. Sts. 934, 929.

### Family ERYCINIDAE

*Notolepton* cf. *antipodum* (Filhol, 1880). St. 933. (c.)

***Notolepton sublaevigatum***, n.sp. St. 933. (c.)

***Notolepton subobliquum***, n.sp. St. 933. (c.)

***Mysella aupouria***, n.sp. St. 933.

***Mysella alpha***, n.sp. St. 933.

***Mysella beta***, n.sp. St. 933.

*Myllitella vivens*, Finlay, 1926. St. 931.

*Pachykellya edwardsi*, Bernard, 1897. St. 933.

****Borniola neozelanica***, n.sp. St. 933.

*Cyamiomactra problematica truncata*, Suter, 1907. St. 929.

### Family MACTRIDAE

*Scalpomactra scalpellum* (Reeve, 1854). St. 929.

### Family VENERIDAE

*Dosinia* (*Phacosoma*) *maoriana* (Oliver, 1923). St. 929.

*Paradione* (*Notocallista*) *multistriata* (Sowerby, 1851). St. 930.

*Tawera spissa* (Deshayes, 1835). St. 929.

*Gomphina* (*Gomphinella*) *maorum*, Smith, 1902. St. 934.

### Family CARDIIDAE

*Nemocardium* (*Pratulum*) *pulchellum* (Gray, 1843). St. 931

### Family SANGUINOLARIIDAE

*Ascitellina urinatoria* (Suter, 1913). St. 933.

### Family THRACIIDAE

*Parvithracia triquetra* (Suter, 1913). St. 933.

***Parvithracia cuneata***, n.sp. St. 934.

### Family MYOCHAMIDAE

*Myadora novaezelandiae*, E. A. Smith, 1880. St. 931.

### Family VERTICORDIIDAE

*Verticordia* (*Haliris*) *setosa* (Hedley, 1907). St. 933.

### Family CUSPIDARIIDAE

*Cuspidaria traílli* (Hutton, 1873). St. 931.

****Austroneaera brevirostris***, n.gen. et sp. St. 933.

## Gasteropoda

### Family SCISSURELLIDAE

***Scissurella manawatawhia***, n.sp. St. 933.

*Schizotrochus mantelli*, Woodward, 1859. St. 933. (c.)

***Schizotrochus aupouria***, n.sp. St. 933.

***Schizotrochus finlayi***, n.sp. St. 934.

*Schismope lyallensis*, Finlay, 1926. St. 933.

*Schismope laqueus*, Finlay, 1926. St. 933.

### Family FISSURELLIDAE

*Emarginula striatula*, Quoy and Gaimard, 1834. Sts. 929, 934.

*Monodilepas diemenensis*, Finlay, 1930. Sts. 933, 934.

****Zeidora maoria***, n.sp. St. 933.

***Puncturella manawatawhia***, n.sp. St. 933.

### Family STOMATELLIDAE

***Herpetopoma benthicola***, n.sp. Sts. 933, 934.

### Family TROCHIDAE

*Trochus* (*Thorista*) *camelophorus*, Webster, 1906. St. 934.
***Thoristella crassicosta***, n.sp. St. 933.

### Family CALLIOSTOMATIDAE

*Fautor onustus* (Odhner, 1924). St. 934.
***Zeminolia luteola***, n.sp. St. 933.
***Zeminolia vera***, n.sp. Sts. 929, 931.
***Zeminolia benthicola***, n.sp. St. 933.

### Family LIOTIIDAE

***Munditia aupouria***, n.sp. Sts. 933, 934.
***Munditia echinata***, n.sp. St. 933.
***Munditia manawatawhia***, n.sp. St. 933.
*Liotella indigens*, Finlay, 1926. St. 933.
***Liotella aupouria***, n.sp. St. 933. (c.)
***Liotella rotuloides***, n.sp. St. 933.
***Brookula annectens***, n.sp. St. 933.
*Brookula* (*Aequispirella*) *finlayi*, Powell, 1933. St. 933.
*Lodderina formosa*, Powell, 1930. St. 933.
*Cirsonella consobrina*, Powell, 1930. St. 933.
***Cirsonella paradoxa***, n.sp. St. 933.
***Cirsonella pisiformis***, n.sp. St. 933.
***Cirsonella laxa***, n.sp. St. 933.
***Cirsonella waikukuensis***, n.sp. St. 930.
***Cirsonella simplex***, n.sp. St. 933.
****Starkeyna maoria***, n.sp. St. 933.
***Lissotesta caelata***, n.sp. St. 933.
***Lissotesta aupouria***, n.sp. St. 933.
***Lissotesta conoidea***, n.sp. St. 933.
***Crosseola favosa***, n.sp. Sts. 933, 934.
***Crosseola intertexta***, n.sp. St. 933.
*Dolicrossea vesca*, Finlay, 1926. St. 934.
***Conjectura atypica***, n.sp. St. 933.

### Family ORBITESTELLIDAE

*Orbitestella toreuma*, Powell, 1930. St. 933.

### Family TURBINIDAE

*Argalista nana*, Finlay, 1930. Sts. 933, 934. (c.)
***Argalista rotella***, n.sp. St. 933.
***Argalista variecostata***, n.sp. St. 933, 934. (c.)
*Astraea heliotropium* (Martyn, 1784). St. 929.

### Family PATELLOIDIDAE

*Asteracmea* cf. *suteri* (Iredale, 1915). St. 933.

### Family LEPETIDAE

***Tectisumen subcompressa***, n.sp. St. 933.
***Tectisumen finlayi***, n.sp. St. 934.
*Tectisumen clypidellaeformis* (Suter, 1908). St. 933.

### Family FOSSARIDAE

***Fossarus aupouria***, n.sp. St. 933.
****Fossarus***[1] ***maoria***, n.sp. St. 933.

### Family RISSOIDAE

***Haurakia finlayi***, n.sp. St. 933.
***Haurakia aupouria***, n.sp. St. 933.
***Haurakia duplicata***, n.sp. St. 933.
***Haurakia duplicata exuta***, n.subsp. St. 933.
****Haurakiopsis pellucida***, n.gen. et sp. Sts. 933, 934. (c.)
***Austronoba iredalei***, n.sp. St. 933.
***Merelina paupereques***, n.sp. Sts. 933, 934.
*Merelina compacta*, Powell, 1927. St. 933.
***Merelina manawatawhia***, n.sp. St. 933.
***Merelina crispulatus***, n.sp. St. 933.
***Merelina cochleata***, n.sp. St. 933.
***Merelina crassissima***, n.sp. St. 934.
*Promerelina coronata* Powell, 1926. St. 932.

---

[1] The species referred to *Fossarus* by Odhner, 1924 (*New Zealand Mollusca*. Papers from Mortensen's Pacific Exped. 1914–1916, No. 19, p. 18) have been placed elsewhere by Finlay, 1926 (Trans. N.Z. Inst., LVII, p. 376).

***Promerelina tricarinata***, n.sp. St. 934.
***Nobolira cochlearella***, n.sp. Sts. 933, 934.
*Nobolira bollonsi*, Powell, 1930. Sts. 933, 934.
***Nobolira manawatawhia***, n.sp. St. 934.
***Estea crassicarinata***, n.sp. St. 933.
*Estea angustata*, Powell, 1927. St. 933.
***Estea porrectoides***, n.sp. St. 933.
***Estea crassicordata***, n.sp. St. 933.
***Estea subrufa***, n.sp. St. 933.
***Estea manawatawhia***, n.sp. Sts. 932, 933.
*****Coenaculum secundum***, n.sp. St. 933.
****Manawatawhia analoga***, n.gen. et sp. Sts. 933, 934.
*Epigrus striatus*, Powell, 1927. Sts. 933, 934.
***Notosetia subgradata***, n.sp. St. 933.
***Notosetia aoteana***, n.sp. St. 933.
***Notosetia porcellanoides***, n.sp. St. 933.
***Notosetia subtenuis***, n.sp. St. 933.
***Notosetia aupouria***, n.sp. St. 933.
*Notosetia unicarinata*, Powell, 1930. St. 933.
*Notosetia micans* (Webster, 1905). St. 933.
*Scrobs crassiconus*, Powell, 1933. St. 933. (c.)
*Scrobs ovata*, Powell, 1927. St. 933.
*Notoscrobs erosa* (Odhner, 1924). St. 933.

### Family RISSOINIDAE

*Rissoina achatina*, Odhner, 1924. St. 933.
***Rissoina aupouria***, n.sp. Sts. 933, 934.
***Rissoina achatinoides***, n.sp. St. 930.
***Rissoina manawatawhia***, n.sp. St. 934.
*Rissoina fucosa*, Finlay, 1930. St. 929.
***Dardanula pallida***, n.sp. St. 933.
***Dardanula tenella***, n.sp. St. 934.
***Dardanula minutula***, n.sp. St. 933.
*Dardanula roseola* (Iredale, 1915). St. 933.
***Dardanula roseospira***, n.sp. St. 934. (c.)
*Nilsia conica* (Odhner, 1924). St. 933.
*Scrupus hyalinus* (Odhner, 1924). St. 933. (c.)

### Family CERITHIIDAE

*Zebittium editum*, Powell, 1930. St. 933.
***Zebittium laevicordatum***, n.sp. St. 933.
*Ataxocerithium huttoni* (Cossmann, 1895). St. 934.
***Zaclys paradoxa***, n.sp. St. 934.
*Zaclys sarissa* (Murdoch, 1905). St. 934.
*Sundaya tuberculata*, Powell, 1927. St. 934.
*Joculator caelata*, Powell, 1930. St. 934.
*Alipta crenistria* (Suter, 1907). St. 934.
***Mendax attenuatispira***, n.sp. St. 933.
****Paramendax apicina***, n.gen. et sp. St. 933.
*Socienna elegantula* (Powell, 1930). St. 933.

### Family TRIPHORIDAE

***Notosinister aupouria***, n.sp. St. 933.
*Notosinister fascelina* (Suter, 1908). St. 933.

### Family VERMETIDAE

***Vermicularia maoriana***, n.sp. St. 933.

### Family TURRITELLIDAE

*Zeacolpus vittatus* (Hutton, 1873). St. 934.

### Family CALYPTRAEIDAE

*Sigapatella terraenovae*, Peile, 1924. St. 929.

### Family NATICIDAE

*Proxiuber* cf. *australis* (Hutton, 1878). St. 931.
*Uberella*, n.sp. aff. *vitrea* (Hutton, 1873). St. 933.

### Family LAROCHEIDAE

***Larochea secunda***, n.sp. St. 933.

### Family LIPPISTIDAE

*Zelippistes benhami* (Suter, 1902). St. 933.

### Family CYPRAEIDAE

*Ellatrivia memorata* (Finlay, 1926). St. 934.

### Family AMPHIPERATIDAE

***_Pedicularia maoria_**, n.sp. St. 933.

### Family EPITONIIDAE

*Murdochella levifoliata* (Murdoch and Suter, 1906). St. 933.
*Murdochella tertia*, Finlay, 1930. St. 933.
***Aclis maoria***, n.sp. St. 933.

### Family ARCHITECTONICIDAE

*Zerotula hedleyi* (Mestayer, 1916). St. 933.
***Zerotula triangulata***, n.sp. St. 933.
***Zerotula crenulata***, n.sp. St. 933.

### Family PYRAMIDELLIDAE

*Eulimella larochei*, Powell, 1930. St. 930.
***Eulimella aupouria***, n.sp. St. 934.
*Syrnola* cf. *menda*, Finlay, 1926. St. 933.
*Chemnitzia* cf. *finlayi*, Powell, 1926. St. 930.
***Chemnitzia lawsi***, n.sp. St. 934.
*Graphis blanda* (Finlay, 1924). St. 930.

### Family EULIMIDAE

***Balcis bollonsi***, n.sp.
***Balcis aupouria***, n.sp. St. 933.
*Teretianax pagoda*, Powell, 1926. St. 933.

### Family MITRIDAE

*Austromitra angulata* (Suter, 1908). St. 934.
***Egestas dissimilis***, n.sp. St. 933.
*Peculator coma* (Odhner, 1924). Sts. 929, 931, 932.

### Family PYRENIDAE

***Zemitrella sericea***, n.sp. St. 933.
***Zemitrella annectens***, n.sp. Sts. 933, 934.
***Zemitrella turgida***, n.sp. St. 933.
***Zemitrella curvirostris***, n.sp. St. 933.
*Macrozafra* cf. *nodicincta* (Suter). St. 933.
***_Antimitrella laxa_**, n.gen. et sp. St. 933.
*Liratilia conquisita* (Suter, 1907). Sts. 933, 934.
*Liratilia angulata* (Suter, 1908). Sts. 933, 934.
***Liratilia sinuata***, n.sp. St. 933.
***Liratilia elegantula***, n.sp. St. 934.

### Family VOLUTIDAE

*Microvoluta biconica* (Murdoch and Suter, 1906). St. 933.

### Family OLIVIDAE

*Baryspira* (*Alocospira*) *novaezelandiae* (Sowerby). Sts. 929, 933.

### Family MARGINELLIDAE

***Marginella (Glabella) aupouria***, n.sp. St. 933.
***Marginella (Glabella) manawatawhia***, n.sp. St. 933.
***Marginella (Glabella) pygmaeiformis***, n.sp. St. 934.
*Marginella* (*Serrata*) *aoteana*, Powell, 1932. St. 933.
***Marginella (Serrata) subamoena***, n.sp. St. 932.
*Marginella angasi*, Crosse, 1870. Sts. 933, 934. (c.)
*Gibberula ficula* (Murdoch and Suter, 1909). St. 933.
***Closia maoria***, n.sp. St. 933.

### Family TURRIDAE

***_Nepotilla finlayi_**, n.sp. St. 933.
***Stilla paucicostata***, n.sp. St. 933.
***Mitrithara granulifera***, n.sp. St. 933.
***Mitrithara regis***, n.sp. St. 933.
*Veprecula cooperi*, Mestayer, 1919. St. 933.

### Family CLIIDAE

*Cavolina inflexa* (Lesueur, 1813). St. 934.
*Diacria trispinosa* (Lesueur, 1821). 934.

### Family SPIRATELLIDAE

*Embolus inflatus* (D'Orbigny, 1836). St. 933.
*Spiratella australis* (Eyd. and Soul., 1840). St. 933.

### Family RETUSIDAE

*Retusa cookiana* (Suter, 1909). St. 933. **Retusa aupouria**, n.sp. St. 933.

### Family SCAPHANDRIDAE

*Cylichnina thetidis* (Hedley, 1903). St. 933.

## Amphineura

### Family LEPIDOPLEURIDAE

***Parachiton textilis**, n.sp. St. 934.

### Family CRYPTOCONCHIDAE

**Notoplax aupouria**, n.sp. St. 934. **Notoplax websteri**, n.sp. St. 934.

The collection thus contains 234 species of which 128 have not hitherto been described. There are six new genera, and thirteen which have not previously been reported from New Zealand waters. In the systematic account which follows descriptions are given of two additional new species from other sources.

# SYSTEMATIC ACCOUNT

## Class PELECYPODA

### Family NUCULIDAE

### Genus **Pronucula**, Hedley, 1902

Type (original designation): *Pronucula decorosa*, Hedley

**Pronucula maoria**, n.sp. (Plate XLV, fig. 8).

Shell minute, ovate-rhomboidal, inflated, very thin, fragile. The only sculpture, apart from regular spaced concentric growth lines, is in the form of subobsolete delicate dense radial striae, which are only just visible on the exterior near to the ventral margin, but form a crowded weak crenulation on the inner edge of the valve. Beaks bluntly rounded, set at about the posterior fourth. Hinge plate arched, extremities separated by a broad triangular chondrophore, anterior side with five squarish teeth, posterior side with three. Colour dull silvery white.

Length 1·8 mm.; height 1·5 mm.; thickness (one valve) 0·55 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Two other recent species are known from the New Zealand region: *P. mesembrina*, Hedley, 1916, from 60 fathoms off Macquarie Island, and *P. tenuis*, Powell, 1927, from 100 fathoms off Puysegur Point, south-west Otago.

## Family NUCULANIDAE

### Genus **Nuculana**, Link, 1807

### Subgenus **Jupiteria**, Bellardi, 1875

Type (by subsequent designation, Dall, 1898): *Nucula concava*, Bronn., Pliocene, Italy

**Nuculana (Jupiteria) manawatawhia**, n.sp. (Plate XLV, fig. 9).

Shell small, oval, inflated; beaks bluntly rounded, situated slightly in front of the middle. Anterior and posterior ends narrowly convex, similar, except that the posterior dorsal slope is lower and in consequence that end is a trifle more narrowly rounded than the anterior. Rostrum ill defined, having only the faintest semblance of a bounding ridge. Sculpture of faint low bevelled concentric ridges, about eighteen per millimetre, which are strongest at the middle of the valves, but fade away almost entirely towards the margins and beaks. Hinge strong, with nine anterior and eight posterior chevron-shaped teeth. Pallial sinus shallow, its apex broadly U-shaped. Colour white.

Length 4·2 mm.; height 2·9 mm.; thickness 1 mm. (Holotype, one right valve).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Marwick has described seven Tertiary species of the subgenus *Jupiteria* from New Zealand, but the above new species makes the first record of this subgenus from the New Zealand Recent fauna.

The species here described is not quite typical of the subgenus *Jupiteria*, but it seems to be better placed there than in any other subgenus so far described. It closely resembles Dall's *Leda solidifacta* (1886, *Bull. Mus. Comp. Zool.*, XII, p. 252), which Woodring (1925, *Mioc. Moll. Bowden Jamaica*, Carnegie Publication No. 366, p. 19) has accepted as a *Jupiteria*.

## Family LIMOPSIDAE

### Genus **Aupouria**, n.gen.

Type: *Aupouria parvula*, n.sp.

This genus is related to *Austrosarepta*, Hedley, 1899, but differs in having the resilium pit shaped like an inverted U, and apart from the vertically striated ligamental areas, it has, on the anterior end only, a pair of prominent transverse interlocking hinge teeth. In shape the shell is suborbicular, resembling somewhat a juvenile *Glycymeris*. The allied genus, *Austrosarepta*, has vertically striated ligamental areas also; but the resilium pit is broadly triangular, the marginal hinge teeth are developed at both extremities of the striated areas, and the outline of the shell is obliquely ovate to trapezoidal. The writer has a second species of *Aupouria* from the mid-Pliocene of New Zealand.

**Aupouria parvula**, n.sp. (Plate XLV, fig. 1).

Shell minute, solid, valves only slightly convex, suborbicular, inequilateral, beaks at about the posterior third. Anterior end broadly rounded, produced. Posterior end truncated medially, causing a weak subangle with the basal margin. Prodissoconch large, capped by a rounded boss and marked off by a thin bounding rim. Sculpture of numerous indistinct and somewhat irregular concentric growth lines. Hinge plate broad, arcuate. Resilium pit deep, shaped like an inverted U; on either side of it a vertically striated ligamental area, and below, upon the anterior distal portion of the hinge plate only, there are two short transverse rather strong teeth, which interlock with a pair of similar teeth in the opposite valve. Muscle scars oval, deeply impressed, pallial line simple. Colour white.

Length 1·6 mm.; height 1·5 mm.; thickness (one valve) 0·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 260 m.

Thiele's *Limopsilla* (1923, *Zool. Anzeiger*, LV, Nos. 11–13, p. 289) proposed for *Limopsis pumilio*, Smith, is not applicable to the species here described. While there is a certain similarity in shape, and a correspondingly small size, the hinge details of the two are irreconcilably diverse, that of *pumilio* being particularly strong and massive for the size of the shell.

## Family PHILOBRYIDAE

### Genus **Cosa**, Finlay, 1926

Type (original designation): *Hochstetteria costata*, Bernard

**Cosa serratocostata dispar**, n.subsp. (Plate XLV, fig. 7).

Shell small, rhomboidal, solid, moderately inflated. Colour uniformly buff. Prodissoconch typical. Anterior margin vertical, dorsal margin horizontal, posterior margin almost vertical, ventral margin broadly rounded. Sculpture of fourteen radial ribs which in relative strength fall into two series, there being seven massive radials over the middle area of the shell, the remaining three anterior and four posterior radials being of considerably weaker development. These radials are bold and triangular in section with interstices at the margin wider than the diameter of the ribs. The whole shell is crossed by narrow closely spaced concentric ridges, which imbricate the radials where they surmount them. Ventral margin strongly denticulated by the radial ribbing. Hinge plate narrow and long, chondrophore and vertically grooved extremities of hinge plate typical.

Height 2·2 mm.; diameter 2·1 mm.; thickness (one valve) 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This is a readily separated variant of *serratocostata* (described from shell sand from Tom Bowling Bay) which is characterized by the unequal development of its radials, seven of them over the middle of the shell being disproportionately large. The intercostal spaces also are proportionately wider than in the typical species. Both *serrato-*

*costata* typical and *filholi* occurred in the same dredging with the subspecies here described.

### Genus **Cratis**, Hedley, 1915

Type (original designation): *Cratis progressa*, Hedley, Recent, New South Wales

**Cratis retiaria**, n.sp. (Plate XLV, fig. 4).

Shell small, white, solid, subquadrate, inequilateral; beaks near anterior end. Prodissoconch of moderate size, having a broad well-defined rim and the middle raised to a sharply pointed boss. Anterior margin almost vertical, practically at right angles to the straight hinge line. Posterior margin fairly straight, nearly vertical medially, but rounded off to the hinge plate, and gently curved into the broadly rounded sweep of the basal margin. Sculpture of fairly strong closely spaced concentric ridges, decussated by equally strong and more numerous radials. The radials number about fifty-two, and the concentric ridges about twelve per millimetre, near the margin. The sculpture resolves into a regular pattern of very numerous oval to rectangular raised granules. Hinge typical: chondrophore broadly triangular, oblique, situated immediately below the middle of the prodissoconch. Upper margin of hinge plate crowded with vertical striations. Secondary teeth strong, situated distally, below the striations. Left valve with two anterior vertical teeth, the innermost much the stronger, and three posterior transverse teeth, the middle one of which is strongest. Margin of valves bevelled and without crenulations.

Length 2·5 mm.; height 3 mm.; thickness (one valve) 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is nearest allied to the lower Miocene (Tutamoe Series) *C. ovata*, Marwick, 1931 (*N.Z. Geol. Surv., Pal. Bull.*, 13, p. 60), which is the only previous record of the genus from New Zealand.

The two species here described add this genus to the New Zealand Recent fauna.

**Cratis delicatula**, n.sp. (Plate XLV, fig. 3).

Shell small, white, moderately strong, subquadrate, inequilateral; beaks near anterior end. Prodissoconch small, cap-shaped, with a well-defined rim and a sharply raised boss at the middle. Shaped very like *retiaria* but narrower. Sculpture of fine and numerous closely spaced concentric ridges crossed by thin radials. These radials are arranged in two series, a few widely spaced ones over the anterior area of the shell, and finer, much more numerous and closely spaced ones over the posterior area. Hinge fairly typical; chondrophore narrow, descending obliquely, posteriorly, from immediately below the umbo. Upper margin of hinge plate crowded with vertical striations. Secondary teeth strong, situated distally upon the hinge plate, below the striations. Right valve with one strong anterior vertical tooth shaped like an inverted L, and three posterior transverse teeth. In the left valve there are two anterior teeth which fit on either side of the inverted L tooth of the opposite valve. On the lower part of the posterior margin there are a few faint crenulations.

Length 2·4 mm.; height 3 mm.; thickness (one valve) 0·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

In addition to the two Recent species of *Cratis* described above, there are two Australian species; the genotype, *progressa*, Hedley (1915, *Proc. Linn. Soc. N.S.W.*, XXXIX, p. 698), from 100 fathoms, north-east of Port Macquarie, New South Wales, and *cuboides* (Verco) (1907, *Trans. Roy. Soc. S. Australia*, XXXI, p. 223), from 20 fathoms, Backstairs Passage, South Australia.

## Family PECTINIDAE

### Genus **Cyclopecten**, Verrill, 1897

### Subgenus **Cyclochlamys**, Finlay, 1926

Type (original designation): *Pecten transenna*, Suter, 1913

**Cyclopecten (Cyclochlamys) aupouria** n.sp. (Plate XLVII, figs. 1, 2).

Shell minute, white, inequivalve and inequilateral, thin and fragile, with discrepant sculpture on the two valves. Left valve sculptured with thin regularly spaced concentric lamellae and fine interstitial radial threads. The concentric lamellae are about six per millimetre. Ears subequal, small, not distinctly marked off from the disc. Beaks raised in the form of small rounded knobs. Right valve flatter than the left and sculptured with very much finer thread-like concentric lines, about twenty per millimetre, interspaces with dense microscopic radials. Anterior ear with five thickened concentric folds, posterior with a well-defined byssal sinus, several indistinct radials and radial crenulations along the hinge margin. Interior smooth, hinge line straight with a minute triangular resilium.

Diameter: antero-posterior 3·4 mm., dorso-ventral 2·9 mm.; thickness 0·6 mm. (Holotype, left valve).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

**Cyclopecten (Cyclochlamys) secundus**, Finlay, 1926.

1919. *Pecten* aff. *transenna*, Mestayer, *Trans. N.Z. Inst.*, LI, p. 135, pl. 8, fig. 11.
1926. *Cyclochlamys secundus*, Finlay, *Trans. N.Z. Inst.*, LVII, p. 453.

A figure is provided (Plate XLVII, fig. 3) of what appears to be the right valve of *secundus*. It is delicately sculptured with extremely dense concentric threads chopped up into numerous radial series but with no raised radials showing. The whole effect is an intricate tessellated pattern caused by alternating sections of the concentric ribbing varying in spacing.

Diameter: antero-posterior 2·8 mm.; dorso-ventral 2·4 mm.

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Finlay described his *Cyclochlamys* (*loc. cit.*, 1926, p. 452) as having both right and left valves nodulous but Marwick (1928, *Trans. N.Z. Inst.*, LVIII, p. 453) has shown that the right valve is almost smooth as in true *Cyclopecten*. It will be necessary to compare the genotypes before the status of *Cyclochlamys* can be determined.

## Family DIMYIDAE

### Genus **Dimya**, Rouault, 1850

Type: *Dimya deshayesiana*, Rouault

**Dimya maoria**, n.sp. (Plate XLV, fig. 2).

Shell irregularly ovate, slightly oblique, higher than long. Left valve free, undulating exteriorly, somewhat arched over the upper portion but becoming actually concave before the basal margin is reached. Right valve with a large area of attachment and rather steep short sides. Surface of valves irregularly malleated, but with no true sculpture. Umbo small, projecting, about central, with small deep triangular chondrophore immediately below it. Hinge line straight and rather long. Interior with a deeply incised simple pallial line, outside of which is a broad smooth slightly convex marginal shelf, bearing numerous faint radial riblets, about thirty in the holotype (obscure over the basal and posterior margins). Muscle scars typical, a small oval anterior one high up and a double (figure 8) posterior one situated at about half the height of shell.

Length 6·1 mm.; height 7·7 mm.; maximum thickness 1·5 mm. (Holotype, a left valve).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is characterized by its malleated surface and complete absence of radial sculpture. The genus is new to the New Zealand fauna but occurs in both Recent and Tertiary deposits in New South Wales and Victoria respectively.

## Family LIMIDAE

### Genus **Limatula**, Searles Wood 1839

Type: *Lima subauriculata*, Montagu

**Limatula aupouria**, n.sp. (Plate XLVII, fig. 4).

Shell very small, elongate-ovate, slightly oblique, equivalve and almost equilateral. Beaks bluntly rounded, tip smooth, followed by a brief development of very fine and closely spaced concentric lirae. Ears small, almost equal; the anterior one slightly higher than the posterior. Sculpture consisting of a few strong rounded radial ribs, which are imbricated by sharp concentric lamellae. The radials number seventeen; those at the extremities being indistinct. Also, the radials fade out above at the commencement of the post-embryonic concentric lirations. The later concentric sculpture begins to develop at about two-thirds the height of the shell, after which the riblets become stronger and more lamellose as the margin is approached. The radials are less than half their own width apart and the concentric lamellae about twelve per millimetre. Colour dull white. Hinge plain, resiliary pit broadly triangular. Interior radially indented, corresponding to the external ribbing.

Length 1·6 mm.; height 2·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is allied to *L. insularis*, Oliver, 1915, dredged off Sunday Island, Kermadec Islands. Both are coarsely ribbed and exceedingly small for their genus.

## Family CRASSATELLITIDAE

### Genus **Cuna**, Hedley, 1902

Type (original designation): *Cuna concentrica*, Hedley, Recent, New South Wales

**Cuna aupouria**, n.sp. (Plate XLVI, figs. 1, 2).

Shell minute, solid, oblique-trigonal, equivalve, inequilateral, smooth, dull white. Prodissoconch small, smooth and globular. Beaks directed backwards. Lunule and escutcheon similar, well developed, long and deep. Hinge massive, but constricted laterally by the deeply excavated lunule and escutcheon. Hinge teeth normal; right valve with two divergent cardinals, left with a rudimentary anterior cardinal and a massive triangular posterior one. The slightly thickened anterior edge acts as a lateral, by fitting into a groove in the opposite valve. Basal margin weakly crenulate within. Interior smooth, adductor scars subequal, distinct.

Length 2·1 mm.; height 2·3 mm. (Holotype, a right valve).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species in its smoothness is nearest to *otagoensis*, Powell (1927, *Rec. Cant. Mus.*, III, pt. 2, p. 120), and although the two species are similar also, in outline, the direction of the beaks is opposite. They differ further in the greatly constricted hinge of the new species.

**Cuna waikukuensis**, n.sp. (Plate XLVI, fig. 3).

Shell small, solid, oblique-trigonal, equivalve, inequilateral, smooth, white. Prodissoconch small, smooth and globular. In shape the species is very similar to *aupouria* except that the lunule and escutcheon are very faint, and in consequence there is no constriction of the hinge. The basal margin is weakly crenulated and faintly rayed within, but externally the valves are quite smooth. There are twelve of these subobsolete rays. Hinge normal; right valve with two divergent cardinals, left with a rudimentary anterior cardinal and a massive triangular posterior one. Growth series from young to adult in both species demonstrate that *aupouria* can always be distinguished by the deeply excavated lunule and escutcheon and massive constricted hinge. In *waikukuensis* the reverse obtains, the lunule and escutcheon being poorly developed and the hinge moderate and not constricted.

Length 1·7 mm.; height 1·9 mm. (Holotype, a right valve).

*Habitat:* Off Waikuku Beach, St. 930, 1·8 miles, 035° off North Cape, 29 m.

**Cuna manawatawhia**, n.sp. (Plate XLVI, fig. 5).

Shell small, solid, oblique-trigonal, equivalve, inequilateral, white; sculptured with ten broad flattened radial ribs, with shallow interspaces, of about a third the width of the ribs. Prodissoconch small, smooth and globular. Beaks directed forwards. Anterior end the shorter, dorsal slopes straight to the middle, below which is the broad arcuate sweep of the base, which is produced a little posteriorly. Hinge typical. Lunule and escutcheon well defined, bounded by an angular ridge. Interior smooth, external ribbing showing through only at the basal margin, which is rendered slightly sinuose, hardly crenulate.

Length 2·6 mm.; height 2·9 mm. (Holotype, a left valve).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species is nearest to *C. mayi*, Powell, from 10 to 12 fathoms off Wanganui. It combines the sculpture of this species with a shape similar to that of *C. compressidens*, Powell, from 6 fathoms off Mangonui.

**Cuna gibbosa**, n.sp. (Plate XLVI, fig. 4).

Shell minute, solid, oblique-trigonal, equivalve, inequilateral, smooth, dull white. Prodissoconch small, smooth and globular. Beaks directed forwards and situated near to the anterior end, on account of the high strongly arched posterior dorsal margin, which is subangled at two-thirds the height of the shell. Lunule long and deeply concave, escutcheon not prominent owing to the strongly arched posterior slope. Anterior end subangled at about half the height. Ventral margin broadly rounded but obliquely canted forwards. Valve margins smooth. Hinge abnormal owing to the obliquely humped shape of the shell. Left valve with a rudimentary anterior cardinal and a massive elongate posterior cardinal. Right valve not seen but evidently like that of *otagoensis*, which has a massive anterior obliquely elongate cardinal and a posterior thin lamellate one bordering the dorsal margin.

Length 2·00 mm.; height 2·25 mm.; thickness 0·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is allied to *C. otagoensis*, Powell (1927, *Rec. Cant. Mus.*, III, pt. 2, p. 120), but is more obliquely humped in outline and lacks any trace of radials towards the dorsal margin. It also resembles the Tasmanian *C. hamata*, Hedley and May (1908, *Rec. Austr. Mus.*, p. 124).

## Family CARDITIDAE

### Genus **Pleuromeris**, Conrad, 1867

Type (by monotypy): *Pleuromeris decemcostata*, Conrad (= *Cardita tridentata*, Say)

**Pleuromeris latiuscula**, n.sp. (Plate XLV, fig. 5).

Shell small, subcircular, equilateral, only moderately convex, pale buff, sculptured with twenty rather indistinct broad radial ribs, having linear interspaces. These are crossed somewhat irregularly by numerous very fine concentric growth lines. Prodissoconch minute, smooth and globular. Hinge typical; left valve with two almost equally developed, bluntly triangular, divergent cardinals and an anterior and a posterior lateral;

right valve with a broadly triangular cardinal and two laterals. Margin of valves weakly crenulate along the ventral edge. Muscle scars ovate, subequal.

Length 2·2 mm.; height 2·2 mm.; thickness (one valve) 0·7 mm. (Holotype).

*Habitat:* Off Waikuku Beach, near North Cape, St. 930, 29 m.

**Pleuromeris latiuscula benthicola**, n.subsp. (Plate XLV, fig. 6).

Shell similar to above in all respects except shape, being constantly more broadly triangularly ovate in outline. It is a deep-water relative of the above-described species, but nomenclatural separation is desirable as both forms are quite distinct and constant at their respective stations.

Length 2·6 mm.; height 2·3 mm.; thickness (one valve) 0·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

In their rounded shape these shells resemble *Carditella*, but the hinge characters and the absence of pronounced granulation of the radials are more in accord with *Pleuromeris*.

## Family LUCINIDAE

### Genus **Epicodakia**, Iredale, 1930

Type (original designation): *Epicodakia consettiana*, Iredale, 1930
= *Lucina minima*, Ten.-Woods

**Epicodakia neozelanica**, n.sp. (Plate XLVI, fig. 8).

Shell small, ovate, inequilateral, the posterior side the shorter, moderately convex, with blunt rounded incurved beaks. Sculpture of closely spaced flattish narrow concentric ridges, crossed by almost obsolete closely spaced radials; these show faintly on the anterior end where they render the concentric ridges weakly granulose, but barely show on the rest of the shell. Margins smooth and bevelled. Hinge in left valve with a strong bifid narrowly triangulate cardinal and a well-defined anterior and posterior lateral; right valve with two divergent narrow cardinals and two laterals. Ligament long and narrow, set just within the dorsal margin. Colour dull white.

Length 5·5 mm.; height 4·2 mm.; thickness (one valve) 1·5 mm. (Holotype).

Length 8·0 mm.; height 6·5 mm.; thickness 2·3 mm. (largest paratype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.; St. 929, off Spirit's Bay, northern New Zealand, 59 m.

This species is close to the New South Wales and Tasmanian genotype, but may be distinguished by its more ovate shape and almost obsolete radials. The genus is new to the New Zealand fauna.

## Family ERYCINIDAE

### Genus **Notolepton**, Finlay, 1926

Type (original designation): *Kellia antipoda*, Filhol

**Notolepton sublaevigatum**, n.sp. (Plate XLVII, fig. 7).

Shell small, thin, pellucid white, ovate, broader than high, very little inflated. Beaks small but prominent, inclined forwards. Anterior end slightly shorter than posterior end. Anterior end a trifle more narrowly rounded than posterior end, both broadly and evenly arcuate. Surface polished, showing very faint concentric growth lines but no true sculpture. Hinge typical. Right valve with a large elongate-triangular cardinal at the lower anterior part of the hinge plate, and a long narrow lamella above it, which is hooked downward at its inner extremity; behind the centrally placed resilifer there are two long narrow diverging lamellae. Left valve with an anterior hooked cardinal and a long medially thickened posterior lamella. Interior and valve margins smooth.

Length 2·8 mm.; height 2·3 mm.; thickness (one valve) 0·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from the genotype in being proportionately broader, less inflated, and in having the outer surface smooth except for microscopic growth lines. In *antipoda* there is a regular concentric sculpture of sharp closely spaced ridges.

**Notolepton subobliquum, n.sp.** (Plate XLVII, fig. 6).

Shell small, thin, semi-transparent, white. Subcircular, slightly inflated. Beaks small, pointed, projecting. Anterior end somewhat narrowly rounded, descending sharply from below the beak. Posterior end broadly rounded, dorsal part slightly higher than the umbo. Medial section of the dorsal margin somewhat flattened. Sculptured with closely spaced fine regular sharp concentric threads. Hinge typical. Interior and valve margins smooth.

Length 2·08 mm.; height 1·85 mm.; thickness (one valve) 0·51 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from the genotype in shape, having the umbos set more anteriorly, and the posterior dorsal slope actually higher than the umbo.

### Genus **Mysella**, Angas 1877

Type (by monotypy): *Mysella anomala*, Angas

**Mysella aupouria, n.sp.** (Plate XLVII, fig. 5).

Shell small, solid, white. Inequilateral; anterior end about twice length of posterior end. Beaks low and rounded, tips smooth and globular. Anterior end rounded, much produced. Posterior end short and obliquely truncated below. Hinge typical; right valve with two divergent cardinals, separated by the resilium. The cardinal anterior to the resilium is the larger, being longer and more massive than the second cardinal, which is posterior to the resilium. In the left valve thickened margins interlock with grooves in the opposite valve, which are located between the cardinals and the margin. These thickened margins of the left valve are rudimentary hinge teeth, for they are, at their proximal ends, thickened into two small callosities, which interlock with the cardinals of the other valve. Surface smooth except for regular weakly developed concentric growth lines. Muscle scars ovate subequal. Pallial line with a slight insinuation.

Length 3·5 mm.; height 2·7 mm.; thickness (one valve) 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is very like the New South Wales genotype, which is similarly truncate posteriorly.

**Mysella alpha**, n.sp. (Plate XLVI, fig. 6).

Shell small, rather thin, white, elongate-oval, very oblique. Inequilateral; anterior end greatly produced. Beaks low, tips small, smooth and globular, situated at about the posterior eighth. Dorsal margin straight and horizontal for a little less than half the length of the shell forward from the beaks, where it is weakly subangled, the margin then descending gradually to a somewhat narrowly rounded anterior end. Posterior end very short and steep, broadly rounded. Both ends curve gradually and regularly into the broadly rounded basal margin. Right valve hinge with two divergent cardinals, separated by the resilium and an anterior lateral lamella, which is parallel to the dorsal edge. Left valve with thickened valve margins one on each side of the resilium; these interlock with the cardinals and the lamella of the opposite valve. Valve margins smooth, minutely bevelled. Surface smooth, except for faint unequally spaced concentric lines of growth.

Length 2·15 mm.; height 1·6 mm.; thickness (one valve) 0·45 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is very close to *Montaguia charcoti*, Lamy (1906, *Bull. Mus. Hist. Nat.* XII, pl. 1, figs. 13 and 14) described from Graham Land in the Antarctic, and later recorded from Macquarie Island by Hedley 1916 (*Mollusca, Australasian Ant. Exped.*, IV, p. 32). I have not seen Macquarie Island specimens, but compared with Lamy's excellent figures of the type of the Graham's Land *charcoti* the Three Kings shells differ only in the lateral lamella being much shorter, the anterior cardinal smaller and the dorsal margin slightly subangled above.

**Mysella beta**, n.sp. (Plate XLVI, fig. 7).

Shell larger than *alpha*, more solid, oval, but not so elongate. Dorsal margin, anterior to the beaks, broadly arched. Anterior end greatly produced, broadly rounded; posterior end somewhat narrowly rounded. Beaks low, tips small, smooth, depressed, rounded. Valve margins smooth. Surface smooth, except for unequally spaced concentric lines of growth. Hinge similar to that of *alpha*.

Length 3·3 mm.; height 2·8 mm.; thickness (one valve) 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is close to *alpha*, but grows larger, is not nearly so obliquely elongate-oval, and has more bluntly rounded beaks.

### Genus **Borniola**, Iredale, 1924

Type (original designation): *Bornia lepida*, Hedley

**Borniola neozelanica**, n.sp. (Plate XLVII, fig. 8).

Shell small, thin, white, oblong inequilateral, somewhat compressed, sculptured with densely packed very fine radiate threads, interrupted by well-defined concentric growth lines. Umbo prominent, conical. Anterior end a trifle shorter and more narrowly rounded than posterior. Hinge with two divergent cardinals in the left valve, the posterior one the stronger and in the right valve two lamellae which interlock with the cardinals.

Length 4·55 mm.; height 3·3 mm.; thickness (one valve) 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

The New Zealand species here described seems very similar to the New South Wales genotype. The genus has not previously been found in New Zealand.

## Family THRACIIDAE

### Genus **Parvithracia**, Finlay, 1926

Type (original designation): *Montacuta triquetra*, Suter

**Parvithracia cuneata**, n.sp. (Plate XLVI, fig. 9).

Shell small, solid, white, very inequilateral, wedge-shaped. Beaks low and rounded, tips small, directed backwards, situated at about the posterior tenth of the length. Anterior end greatly produced, gently descending and straight dorsally, narrowly rounded medially, and broadly convex, almost straight, along the ventral margin. Posterior end abruptly truncated, subangled at about half the height and again below at the junction with the ventral margin. Hinge of right valve with a short very oblique triangular cardinal, and a long groove running parallel to, and almost for the entire length of, the anterior dorsal slope. Left valve not seen. Anterior muscle scar elongate-ovate, posterior one circular. Pallial line interrupted by a broad fairly deep sinus.

Length 5·2 mm.; height 3·7 mm.; thickness 1·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

Although the extreme truncation of the posterior end in this species results in a shell of very different outline from that of the genotype, the essential features of hinge and pallial sinus are closely similar.

## Family CUSPIDARIIDAE

### Genus **Austroneaera**, n.gen.

Type *Austroneaera brevirostris*, n.sp.

This genus is proposed for an Austral group of trigonal-shaped *Cuspidaria*-like shells, thin and smooth, with a very poorly developed rostrum. Hinge edentulous in the left valve, an anterior and a posterior lateral in the right valve. There is a broadly rounded pallial sinus.

**Austroneaera brevirostris**, n.sp. (Plate XLVIII, fig. 11).

Shell small, thin, ovate-trigonal, almost equivalve, white; rostrum short, truncated. Anterior and posterior dorsal slopes fairly straight. Ventral margin gently convex, barely incurved at the base of the broad truncated rostrum. Anterior end rather narrowly rounded low down on the same level as the rostrum. The lower angle of the rostrum marks a weak angulation which proceeds towards the umbo, but fades out entirely before reaching it. Sculpture of weak microscopic closely spaced concentric growth lines. Hinge of left valve edentulous, that of right valve with an anterior and a posterior lateral, the latter being lamellate triangular and projecting forwards into the left valve. There is a broad rounded pallial sinus.

Length 4·4 mm.; height 2·9 mm.; thickness (one valve) 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

**Austroneaera finlayi**, n.sp. (Plate XLVIII, fig. 12).

Shell small, thin, trigonal, almost equivalve; rostrum abruptly truncated. Anterior and posterior dorsal slopes fairly straight, sharply and uniformly descending. Ventral margin convex, barely incurved below the truncated rostrum. Anterior end rather narrowly rounded low down on the same level as the rostrum. No clearly defined angle separating the rostrum from the rest of the shell. Surface smooth except for very faint irregular concentric growth lines. Hinge of left valve edentulous, that of right valve with an anterior and a posterior lateral, the latter being lamellate triangular as in the preceding species. Resilium large triangular, set slightly posterior to the beak.

Length 3·5 mm.; height 2·5 mm.; thickness (one valve) 0·7 mm. (Holotype).

*Habitat:* 60 fathoms off the Poor Knights Islands.

*Holotype* in the collection of Dr H. J. Finlay, Dunedin, New Zealand.

This species closely resembles the genotype, from which it differs mostly in shape, being proportionately much shorter.

## Class GASTEROPODA

### Family SCISSURELLIDAE

### Genus **Scissurella**, d'Orbigny, 1824

Type: *Scissurella costata*, d'Orbigny

**Scissurella manawatawhia**, n.sp. (Plate XLIX, fig. 1).

Shell minute, thin, white, ovate, sculptured with strong oblique squarish radial cords and less conspicuous spiral threads. Whorls $3\frac{1}{4}$, including a minute flattened radially ribbed protoconch of $1\frac{1}{4}$ whorls. Spire about one-third height of aperture. The radials number sixteen on the last whorl and they extend from the suture to the minute umbilical chink except for the interruption of the fasciole girdle, which is sunken, with raised edges, and is situated above the middle of the whorls. The fasciole girdle commences at the close of the penultimate whorl. Slit deep, extending back over about one-third of the body whorl. There are four equispaced spiral threads between the fasciole girdle and the upper suture and nine below the girdle on the body whorl and base. Aperture oblique-oval. Peristome thin, continuous across parietal wall, broken only by the slit.

Height 1·05 mm.; diameter 1·0 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species appears to be more nearly allied to the Tasmanian *S. ornata*, May, than to any of the New Zealand species.

### Genus Schizotrochus, Monterosato, 1877

Type: *Scissurella crispata*, Fleming

**Schizotrochus aupouria**, n.sp. (Plate XLIX, fig. 3).

Shell small, depressed trochiform, very thin, narrowly umbilicate, white. Spire low, gradate, about one-third height of aperture. Besides the usual sharp double keels enclosing the deep narrow anal fasciole there are two rounded keels on the middle of the base. These are separated by a shallow depression only, making them appear as one broad spiral fold. Whorls $3\frac{1}{4}$, including a smooth planorbid protoconch of $1\frac{1}{4}$ whorls followed by a brephic stage of four sharp radials. Post-nuclear whorls sculptured with exceeding fine and crowded sharp radial riblets, those on the base being flexuous where they cross the keels. Umbilicus small, overhung by the thin reflected inner lip. In the sloping concavity leading to the umbilicus there are a few indistinct spiral striations. Aperture diamond-shaped. Peristome thin, continuous, except for the deep anal slit which runs back over nearly half the body whorl.

Height 0·9 mm.; diameter 1·25 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is not the juvenile of *S. mantelli* (Woodward, 1859) (= *S. regia*, Mestayer, 1916). Series of both species have been examined, showing that *mantelli* at all stages has an evenly convex base, whereas *aupouria* always has the heavy bicarinate basal fold.

**Schizotrochus finlayi**, n.sp. (Plate XLIX, fig. 2).

Shell small, depressed trochiform, very thin, narrowly umbilicate, white. Spire low, gradate, about two-thirds height of aperture. Peripheral double keel strong with sharp lamellar edges. Sculpture of crisp lamellar radials, those on the base being finer and much more closely spaced than those above. The radials number twenty-two on the upper surface and about sixty on the base. Interstices crowded with fine spiral lirations, there being about twelve between the suture and the peripheral keels.

Height 1·7 mm.; diameter 1·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This makes the third Recent species of the genus found in New Zealand. The distinctive character of *finlayi* is the discrepant sculpture, few wide-spaced radials above and much more numerous finer radials below.

## Family FISSURELLIDAE

### Genus **Zeidora**, A. Adams, 1860

Type (by monotypy): *Zeidora calceolina*, A. Adams, 1860. Straits of Korea in 63 fathoms

**Zeidora maoria**, n.sp. (Plate XLVIII, figs. 9, 10).

Shell small, long and narrow; back broadly arched, beak obliquely incurved. Anal fasciole well marked but shallow, extending full length of the dorsal surface of shell. Slit extending in from the margin for about one-fourth the length of shell. Sculpture very fine and delicate, minutely latticed with closely spaced concentric lirae, crossed by dense divaricating radials. The radials are more closely spaced than the concentric lirae, which results in the rectangular interspaces being twice as long as they are broad. Internal shelf well developed (broken in holotype), and extending for more than one-third the length of the shell; edge of shelf concave, slightly flattened medially. Edges of the shell minutely crenulated. Colour white.

Length 2·9 mm.; breadth 1·4 mm.; height 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This adds another genus to the New Zealand fauna. The species is allied to the Australian *Z. tasmanica*, Beddome, 1883, but is more elongate; in fact it more closely resembles *Z. naufraga*, Watson (*Challenger Reports*, *Zool.*, xv, pl. 4, fig. 3) from off Culebra Island, West Indies, in 390 fathoms. The main difference is in the sculpture, the interstices of the reticulate ribbing being square in the West Indian species and oblong in the New Zealand one.

### Genus **Puncturella**, Lowe, 1827

Type: *Patella noachina*, Linn

**Puncturella manawatawhia**, n.sp. (Plate XLVIII, figs. 7, 8).

Shell minute, conical, oval with somewhat flattened sides, thin. Fissure roughly diamond-shaped, almost central, with the characteristic spiral incurved apex immediately behind and inclined to the right. Surface sculptured with about twenty-four radial series of minute deciduous triangularly projecting scales. Both slopes straight, anterior a little shorter. Interior with a typical straight-edged septum half covering the fissure. Colour dull white.

Length 1·5 mm.; breadth 1·15 mm.; height 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

The only other New Zealand species are *demissa*, Hedley, 1904, which differs in having the summit near to the posterior end and the surface practically smooth, and Hedley's record (1916, *Aust. Antarctic Exped.*, *Zool.* IV, pt. 1, p. 37) of *Puncturella analoga*, Martens, from 60 fathoms off the south end of Macquarie Island.

Iredale (1924, *Proc. Linn. Soc. N.S.W.*, XLIX, p. 221) proposed *Vacerra* for the New

Zealand *demissa*, but this name has been included in the synonymy of *Puncturella* by Cotton and Godfrey (1934, *South Aust. Nat.*, xv, No. 2, p. 54).

Although so small the above-described species has the essential characteristics of the genus.

## Family STOMATELLIDAE

### Genus Herpetopoma, Pilsbry, 1889

Type (original designation): *Euchelus scabriusculus*, Ad. and Ang.

**Herpetopoma benthicola**, n.sp. (Plate XLIX, fig. 13).

Shell small, solid, conic. Whorls five, including a small depressed protoconch of $1\frac{1}{2}$ whorls, consisting of one whorl smooth, globular, slightly tilted and inrolled, and a half-whorl of rather distant thin axial plications. Spire tall, about $1\frac{1}{4}$ times height of aperture. Post-nuclear whorls with three rather narrow rounded spiral keels which are crossed by crisp lamellate axials. Points of intersection raised as hollow-fronted spinose scales. The uppermost spiral keel is just below the upper suture and is not strongly developed, the second is situated at the middle and is much stronger, whilst the third is just above the lower suture, and is the most prominent. On the base there are four more spiral keels, the uppermost proceeding from the suture being strongest, the other three regularly diminishing slightly towards the aperture. The interspaces between the spiral and axial sculpture are approximately square and the distance between the spiral keels double the width of the keels. Aperture subcircular, thickened and iridescent within. Columella smooth, concave with a narrow basal notch and a small denticle on each side of it, followed by further weak denticles which correspond to the terminal points of the external spiral sculpture. There is no umbilical chink. Colour pure white, not shining, with a few scattered sepia spots which occur in no set order but always at points of sculptural intersection.

Height 3·5 mm.; diameter 3 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 260 m.

This is a benthic relative of the littoral *H. larochei*, Powell, 1926, which differs in being depressed conical, with more numerous axial plications, the points of intersection being beaded rather than scaly. Furthermore, the littoral shell is larger and more stoutly built.

## Family TROCHIDAE

### Genus Thoristella, Iredale, 1915

Type (original designation): *Polydonta chathamensis*, Hutton, 1873. Chatham Islands

**Thoristella crassicosta**, n.sp. (Plate XLIX, figs. 14, 15).

Shell small, solid, depressed conical. Spire low, less than height of aperture, sides stepped. Whorls bi-angled, one angle at periphery and the other above the middle. Protoconch smooth, low, first whorl rounded, but the second showing a faint indication of the upper angle, which becomes a prominent feature of the post-nuclear whorls. The post-nuclear sculpture consists of a few strong spiral ridges. On the spire there are three primary ridges and a fourth at the periphery; between these primary ribs there is in each interspace a spiral thread, but these are weak, with the exception of a moderately strong one between the third and the peripheral ridges. On the base there are four broad and strong evenly developed spiral ridges with interspaces of less than half their own width. There is no umbilicus, but in its place a calloused area with an arcuate shallow groove, which runs parallel to the thickened pillar. Colour pale buff, intercostal spaces light brown, interior iridescent.

Height 3·7 mm.; diameter 4·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

## Family CALLIOSTOMATIDAE

### Genus **Zeminolia**, Finlay, 1926

Type (original designation): *Minolia plicatula*, Murd. and Suter

**Zeminolia luteola**, n.sp. (Plate LI, figs. 1, 2).

Shell small, depressed, shining, almost smooth, widely and deeply umbilicate. Whorls 4¼, including typical smooth bulbous protoconch of one whorl, which terminates in a minute varix. Spire low, a little less than height of aperture. The whole of the body whorl and base is smooth, but there is faint spiral sculpture on the spire whorls, being most prominent on the first post-nuclear whorl, thence diminishing and finally disappearing at the commencement of the body whorl. The spiral sculpture consists of six approximately equispaced fine threads on the early whorls, and a variable number over the penultimate, owing to the disappearance of those near to the lower suture and the addition of some intermediate threads above. There is a flat, moderately wide, but ill-defined shoulder to all the post-nuclear whorls, although it is almost obsolete towards the aperture. The deep and wide perspective umbilicus has straight smooth sides and is bordered by a prominent smooth spiral ridge. Aperture subcircular, adnate to parietal wall for a very short space. Peristome thin, columellar portion almost straight, vertical, weakly notched below at the termination of the circumumbilical ridge. Colour: protoconch chrome, following whorl bright lemon yellow and then merging into the general ground colour of pale pinkish buff. There is a faint colour pattern of widely spaced narrow chevrons of light red, one series just below the suture and the other at the periphery.

Height 4 mm.; major diameter 5·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

In shape this species is near to the genotype, but the sculpture and coloration differ considerably.

**Zeminolia vera**, n.sp. (Plate LI, fig. 3).

Shell small, depressed, finely lirate, shining, widely and deeply umbilicate. Whorls 4¼, including typical smooth bulbous protoconch of one whorl. Spire low, a little less than height of aperture. Sculpture of post-nuclear whorls consisting of fine closely spaced lirations, nine on the penultimate whorl and about thirty on the body whorl, ten of these being between the upper suture and the periphery and the remaining twenty (which are finer and more closely spaced) from the periphery over the base to the ridge that margins the umbilicus. There is a moderately wide ill-defined subsutural shoulder bearing weak closely spaced short radials which at most inconspicuously bead the uppermost spirals only. Umbilicus deep and wide, a little more than one-third the diameter of the shell and bordered by a heavy rounded spiral ridge, which is weakly crenulated by fine axial growth folds. Colour: protoconch buff, early spire whorls lemon yellow, remainder of shell pale ochreous buff. On the dorsal surface only there are a few rather narrow wavy irregular radial bands of reddish brown.

Height 3·5 mm.; major diameter 5·4 mm. (Holotype).

*Habitat:* Off Spirit's Bay, St. 929, 59 m. (type locality); and St. 931, between Spirit's Bay and Three Kings Islands, 95 m.

This species appears to be intermediate between the genotype *plicatula* and *luteola*, described above. It has finer and more numerous spirals than *plicatula* and a heavy spiral rib bounding the umbilicus, resembling that of *luteola*. However, the deeper-water *luteola* differs in being smooth except for the early spire whorls and in having a distinctive colour pattern of light red chevrons in two series, one sutural and the other peripheral.

**Zeminolia benthicola**, n.sp. (Plate LI, fig. 4).

Shell small, turbinate, umbilicate. Whorls five, including small smooth bulbous protoconch of one whorl. Spire a little more than height of aperture. Sculpture of narrow sharply raised spiral ridges, and closely packed fine raised axial threads, which are prominent in the interspaces, but do not surmount the spiral ridges. On the first post-nuclear whorl there are three spiral ridges, four on the second, and additional secondary interstitial ones on the later whorls. On the body whorl there are the four main spiral ridges with a secondary ridge in each interspace, and on the base nine closely spaced rounded spiral ridges extending from just below the periphery to the edge of the umbilicus. Inside the umbilicus there are five rather distantly spaced rounded spiral ridges as well as the closely spaced axials. Umbilicus deep, about one-sixth major diameter of the base. There is a broad flattened subsutural shoulder upon all the post-nuclear whorls. Aperture subcircular, adnate to parietal wall for a very short space. Colour: pale lemon yellow with indistinct radial blotches of darker yellow, and, situated upon the shoulder angle, regularly spaced small squarish blotches of red-brown.

Height 5 mm.; major diameter 5·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is near to *Z. tryphenensis*, Powell, 1930, but is not so depressed, has more sharply defined sculpture, and a narrower umbilicus. The chief feature of the species is its prominent crowded axial threads.

## Family LIOTIIDAE

### Genus **Munditia**, Finlay, 1926

Type (original designation): *Liotina tryphenensis*, Powell

**Munditia aupouria**, n.sp. (Plate L, figs. 3, 4).

Shell small, discoidal, clathrate, very solid, white. Whorls 3½, very rapidly increasing. Protoconch smooth, of one small planorbid whorl. Post-nuclear sculpture of heavy spiral keels crossed by strong radials. In addition, the whole surface of these whorls is sculptured with a dense pattern of fine somewhat flexuous radiating striae. The spiral keels number six on the body whorl, four of them being much stronger than the other two. The four main keels are equal in strength and spacing and form a broad peripheral band, the upper and lower extremities of which form sharp angles with the flattened spire and base respectively. The fifth and sixth keels are much weaker, one being situated midway between the upper suture and the uppermost peripheral keel and the other midway between the lowest peripheral keel and the umbilicus. The radial ribs are strong medially but become obsolete both towards the upper suture and towards the umbilicus. These radials number fourteen on the body whorl, and where they cross the spirals the points of intersection are produced into spinose nodules. Umbilicus open, perspective, about one-third the major diameter of the base. A series of axial ridges project into the umbilicus as irregular teeth-like processes. Aperture circular, with a smooth continuous inner margin and a heavy variced finely concentrically striated outer lip.

Height 1·7 mm.; major diameter 3·5 mm.; minor diameter 2·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 260 m.

**Munditia echinata**, n.sp. (Plate L, figs. 5, 6).

Shell very small, discoidal, solid, heavily spinose, white. Whorls 2½, very rapidly increasing. Protoconch small, of one smooth planorbid whorl. Post-nuclear sculpture of three spiral rows of long spines, which fall into vertical series but are not connected by varices. The middle series of spines at the periphery is much stronger than the other two which occupy the spire and base respectively, both being equidistant from the peripheral series and situated nearer to it than to the sutures. There are twelve vertical series of spines on the body whorl. Surface smooth and polished except for faint axial growth lines. Umbilicus widely open, perspective, less than one-third the major diameter of the base. Aperture circular. Peristome thin, slightly expanded, continuous, separated slightly from the parietal wall.

Height 0·6 mm.; major diameter 1·4 mm.; minor diameter 1·05 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Distinguished from other members of its genus by the heavily spinose sculpture.

**Munditia manawatawhia**, n.sp. (Plate L, figs. 1, 2).

Shell very small, white, shining, discoidal, solid. Whorls 2½, very rapidly increasing. Protoconch small, of one smooth planorbid whorl. Post-nuclear sculpture of strong sharp regularly spaced axials, fourteen on the last whorl. These axials extend from the upper suture right over the body whorl and base and into the umbilicus. In addition there are four equispaced spiral threads of less than half the strength of the axials. These spirals do not surmount the axials but they have the effect of rendering the latter somewhat angulate. Surface of shell smooth and polished. Umbilicus wide, perspective, about one-fourth the major diameter of the base. Aperture circular within. Peristome continuous, smooth, expanded, and angled by the terminal points of the four spirals; adnate to the parietal wall for a very short space.

Height 0·8 mm.; major diameter 1·5 mm.; minor diameter 1·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Closely allied to *M. owengaensis*, Powell, 1933 (*Rec. Auck. Inst. Mus.*, 1, No. 4, p. 195), differing only in having the four spirals more prominent and more widely spaced. In *owengaensis*, which is from the Chatham Islands, the spirals are grouped about the periphery, whereas in *manawatawhia* they extend from midway between the upper suture and the periphery to a corresponding position on the base.

### Genus **Liotella**, Iredale, 1915

Type (original designation): *Liotia polypleura*, Hedley

**Liotella aupouria**, n.sp. (Plate LI, fig. 9).

Shell minute, discoidal, thin, white, widely umbilicate, densely radially ribbed. Whorls 3½, including a typical low convex smooth protoconch of 1¼ whorls. Spire not raised above the body whorl. Sculpture consisting of very numerous strong radial rounded riblets (forty-five on the last whorl) with interspaces at the periphery, 1–1½ times the width of the ribs. At the suture the riblets are crowded together with only linear interspaces, and the last four riblets on the body whorl are similarly crowded but for their entire length. The interspaces of the riblets are crowded with fine spiral striations. Umbilicus wide, steep-sided at first but perspective within, about one-third the major diameter of the shell. Aperture circular. Peristome entire, thin.

Height 0·6 mm.; diameter 1·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species resembles *L. neozelanica* (Suter, 1908) from 50 fathoms off the Snares Islands, but is distinct from it in having even closer ribbing, a flat but not sunken spire, and spirally striated instead of smooth intercostal spaces.

**Liotella rotuloides**, n.sp. (Plate LI, fig. 8).

Shell minute, discoidal, thin, white, widely umbilicate, sculptured with numerous radial riblets and dense intercostal spiral striae. Whorls 3¼, including a typical low convex smooth protoconch of 1¼ whorls. Spire flat, not raised above the body whorl. The spiral riblets are prominent and rounded and have the interspaces about three times the width of the riblets, except at the termination of the body whorl where the last five riblets are closely packed. There are twenty-eight radials on the last whorl. Umbilicus wide, rather steep-sided at first but perspective within, one-third the major diameter of the shell. Aperture circular. Peristome entire, thin.

Height 0·7 mm.; diameter 1·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Compared with the allied *L. rotula* (Suter, 1908) from 50 fathoms off the Snares Islands, *rotuloides* differs in having more numerous and closely spaced radials and stronger intercostal spiral striations. The radials in *rotula* average seventeen, compared with twenty-eight in *rotuloides*.

### Genus **Brookula**, Iredale, 1915

Type (original designation): *Brookula stibarochila*, Iredale

**Brookula annectens**, n.sp. (Plate LI, fig. 14).

Shell minute, thin, white, depressed turbinate, perforate. Whorls $3\frac{1}{4}$, including a small smooth globular protoconch of $1\frac{1}{4}$ whorls. Spire same height as aperture, outline of whorls strongly convex. Post-nuclear sculpture of strong sharp-crested axial ribs, with interstices 2–3 times width of ribs, and weak interstitial spiral striations. There are eighteen axials on the body whorl, the last six being more closely spaced, and approximately twelve spiral striations on the penultimate whorl. Umbilicus narrow, about one-ninth major diameter of base. There is no well-marked funicular slope as in the related Upper Pliocene *funiculata*, and the ribs remain straight and undiminished until they reach the umbilical perforation. Aperture circular; peristome thin-edged and separated from the body whorl.

Height 1·1 mm.; diameter 1·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from the related Upper Pliocene *funiculata*, Finlay (1924, *Trans. N.Z. Inst.*, LV, p. 529) in being proportionately taller and in lacking the characteristic funicular depression and variable basal ribbing of that species.

### Genus **Cirsonella**, Angas, 1877

Type: *Cirsonella australis*, Angas

**Cirsonella paradoxa**, n.sp. (Plate L, figs. 15, 16).

Shell small, white, moderately solid, depressed, widely umbilicate. Whorls $3\frac{1}{4}$, including a smooth low convex protoconch of $1\frac{1}{2}$ whorls. Surface of post-nuclear whorls crowded with extremely fine and dense spiral striae. From the umbilicus, which is about one-fifth the major diameter of the base, there are twenty-five strong radial folds. These are strongest at a little distance out from the edge of the umbilicus and fade out entirely at about half way towards the periphery. Spire low, less than half the height of the aperture. Whorls evenly rounded. Aperture circular. Peristome continuous, slightly thickened and actually detached from the parietal wall. A faint spiral joins the lower part of the inner lip.

Height 1·05 mm.; major diameter 1·45 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species bears an extraordinary resemblance to *Argalista rotella*, n.sp., described herein from the same dredge station. Shape, size, umbilicus and basal radial folds are closely similar in both species, but *paradoxa* has the characteristic continuous peristome of *Cirsonella* and dense microscopic spiral striations, while *rotella* has a discontinuous peristome with a thin edge, overhanging above as typical of *Argalista*, as well as fewer and stronger spiral striations.

**Cirsonella pisiformis**, n.sp. (Plate L, figs. 13, 14).

Shell small, white, solid, turbinate, umbilicate. Spire about two-thirds height of aperture. Whorls $3\frac{1}{4}$, including a typical smooth low convex protoconch of one whorl. Post-nuclear whorls smooth except for dense extremely fine and inconspicuous striations. Width of umbilicus about one-seventh major diameter of base. Outer edge of umbilicus crenulated by fourteen short stout radial folds; within there is a spiral cord which curves outwards and downwards joining the lower part of the inner edge of the peristome. Aperture circular. Peristome continuous, slightly thickened and separated by a groove from the parietal wall.

Height 1·3 mm.; major diameter 1·45 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from *paradoxa* in being more globular in shape and in having a much narrower umbilicus.

**Cirsonella laxa**, n.sp. (Plate L, figs. 8, 9).

Shell minute, white, moderately solid, discoidal, widely umbilicate and loosely coiled. Whorls $2\frac{3}{4}$, plus a smooth low convex protoconch of $1\frac{1}{4}$ whorls. Spire not raised above the body whorl. Coiling rapid, latter half of body whorl bent slightly downwards. Sculpture of indistinct spiral cords, crossed by microscopic axial lines of growth. There are five spiral cords on the penultimate whorl, and five on the base that are considerably stronger than the rest. These five stronger basal cords extend from in front of the suture to the edge of the umbilicus. The wall of the umbilicus is smooth and the remainder of the body whorl, apart from the five cords, is crowded with closely spaced fine spiral threads. Umbilicus wide, perspective, about one-third the diameter of the base. Aperture circular. Peristome continuous, slightly thickened, actually detached from the parietal wall, and strongly recurrent at the suture.

Height 0·8 mm.; diameter 1·25 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is characterized by its loose coiling, discoidal shape, aperture recurrent at suture, and lack of umbilical crenulations.

**Cirsonella waikukuensis**, n.sp. (Plate L, figs, 10, 11).

Shell minute, white, solid, depressed turbinate. Spire about half height of aperture. Whorls three, including a typical smooth low convex protoconch of one whorl. Post-nuclear sculpture of indistinct spiral bands marked off by irregularly punctate interstitial grooves. There are about nine spiral bands, indistinct above, the last being situated at about half way across the base. Umbilicus about one-eleventh the maximum width of the shell and around its edge strongly crenulated by axial growth lines. Aperture circular. Peristome continuous, slightly thickened.

Height 0·7 mm., diameter 0·9 mm. (Holotype).

*Habitat:* Off Waikuku Beach, near North Cape, St. 930, 29 m.

**Cirsonella simplex**, n.sp. (Plate L, fig. 12).

Shell minute, turbinate, solidly built, white and glossy, and with a narrow umbilical cavity almost filled with callus. Whorls three, including a small smooth flattened protoconch of one whorl. Spire flat on top, about one-third height of aperture. Whorls convex but with a slightly flattened shoulder. Surface smooth and polished; there is no sculpture. Aperture circular, peristome continuous. Outer lip thin at edge but slightly thickened within. Inner lip much thickened and spread into the umbilical cavity, which is filled except for a crescentic bounding groove on the outer side.

Height 1·4 mm.; diameter 1·75 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species resembles the Tasmanian genotype.

### Genus **Starkeyna**, Iredale, 1930

Type (original designation): *Teinostoma starkeyae*, Hedley

**Starkeyna maoria**, n.sp. (Plate XLIX, figs 10, 11).

Shell small, solid, turbinate, white, glossy; smooth above and spirally striated below. Spire depressed, conoidal, about half the height of aperture. Whorls three, including a low blunt convex protoconch of one smooth whorl. The upper surface of the shell is smooth almost to the periphery, but below this it is closely spirally striate, the striations numbering about thirty-eight and extending right to the funicle. The umbilical cavity is completely filled by the funicle, which is united to the columella as a callous pad. Aperture circular. Peristome thick, continuous.

Height 1·3 mm.; major diameter 1·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This is the first record of this Australian genus from New Zealand waters.

### Genus **Lissotesta**, Iredale, 1915

Type (original designation): *Cyclostrema micra*, Ten. Woods

**Lissotesta caelata**, n.sp. (Plate LI, fig. 5).

Shell minute, globular, moderately solid, white, sculptured with strong rounded spiral ridges. Whorls $3\frac{1}{4}$, including a globular smooth protoconch of $1\frac{1}{2}$ whorls. Spire about two-thirds height of aperture; whorls evenly and strongly convex. Spire whorls with five strong rounded spiral ridges having subequal interspaces; body whorl and base with thirteen ridges, last three with slightly wider interspaces. Umbilicus minute but deep. Aperture subcircular. Outer lip thin, without a varix. Inner lip represented by a thin glaze on the parietal wall. Columella vertical, slightly arcuate and thickened.

Height 0·85 mm.; diameter 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

**Lissotesta aupouria**, n.sp. (Plate LI, fig. 7).

Shell small, turbinate, widely umbilicate, thin, white; sculptured with numerous weak axial threads which become obsolete on entering the umbilicus. Spire about two-thirds height of aperture. Whorls $3\frac{1}{2}$, including a low convex smooth protoconch of $1\frac{1}{4}$ whorls. Aperture ovate-pyriform. Peristome continuous, thin. Suture impressed; slightly shouldered. Umbilicus a little less than one-fourth diameter of shell.

Height 1·9 mm.; diameter 1·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

**Lissotesta conoidea**, n.sp. (Plate LI, fig. 6).

Shell minute, conical, narrowly perforate, thin, semi-transparent white. Spire about $1\frac{2}{3}$ height of aperture. Whorls $5\frac{1}{2}$, including a small low convex protoconch of $1\frac{1}{2}$ whorls. Aperture comparatively small, squarish. Peristome sharp, discontinuous. Columella arcuate, slightly expanded and reflexed below, but excavated in the vicinity of the umbilicus, which is very small but deep. Outline of whorls lightly convex, surface smooth except for moderately strong oblique axial growth lines. Suture false-margined.

Height 1·4 mm.; diameter 1·0 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Genus **Crosseola**, Iredale, 1924

Type (original designation): *Crossea concinna*, Angas

**Crosseola favosa**, n.sp. (Plate LI, fig. 13).

Shell small, white, solid, turbinate-conic, imperforate. Sculpture consisting of moderately strong narrow spiral cords connected axially by cords of equal strength. The axial cords do not cross the spirals in regular series, each series between any two spirals more or less alternating with those of the next series both above and below, the result being a honeycomb effect. There are five spiral cords on the spire whorls and eight on the body whorl, equispaced, except on the shoulder and also just above the fasciole on the base, where in both places the interspace is wider. Spire equal to height of aperture. Whorls $3\frac{3}{4}$, including a small smooth protoconch of one low convex whorl. Aperture circular. Peristome continuous, blunt-edged but not variced. Columella vertical, slightly arcuate and produced below into a broad tongue-shaped process which marks the termination of a heavy axially crenulated basal fold. Imperforate.

Height 1·65 mm.; diameter 1·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 260 m.

This species differs from both *errata*, Finlay, 1926, and *cuvierensis*, Mestayer, 1919, in having more numerous and even spirals, alternating interstitial axials of similar strength, giving a honeycomb effect to the surface of the shell, and no umbilicus.

**Crosseola intertexta**, n.sp. (Plate LI, fig. 12).

Shell small, white, solid, turbinate, imperforate. Sculpture consisting of rather strong, spaced, smooth, spiral cords with thin arcuate closely spaced threads in the interspaces. There are three spiral cords on the spire whorls and seven on the body whorl, the upper three being stronger and more widely spaced than the four on the base. Spire half height of aperture. Whorls $3\frac{1}{4}$, including a small smooth protoconch of one low convex whorl. Aperture circular. Peristome continuous, blunt edged but not thickened, corrugated by the external sculpture. Columella vertical, slightly arcuate, and produced below into a broad tongue-shaped process with a medial groove, which marks the termination of a heavy axially crenulated basal fold. A deep groove separates the basal fold from the inner lip callus, but there is no true umbilicus.

Height 1·8 mm.; diameter 1·65 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This is allied to the previous species but differs from it in having the spiral sculpture predominant over the axial, the upper spirals the stronger, and a much shorter spire.

### Genus **Conjectura**, Finlay, 1926

Type (original designation): *Crossea glabella*, Murdoch

**Conjectura atypica**, n.sp. (Plate LI, figs. 10, 11).

Shell minute, elevated turbinate, moderately solid, white and glossy, having angulate upper whorls, a flattened apex, and narrow crescentic umbilical chink. Whorls $3\frac{1}{2}$, including a tiny planorbid protoconch of $1\frac{1}{2}$ smooth whorls. Spire whorls with a slight shoulder, angulation just above the middle. Body whorl and base evenly convex. Aperture circular, peristome continuous. Outer lip thin; inner lip with a slight callus which is separated from the umbilical chink by a crescentic groove. There are two weak ridges which emerge from the umbilicus and border the lower part of the inner lip.

Height 1·8 mm.; diameter 1·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is not a typical *Conjectura*, but seems to be nearer to that genus than to *Cirsonella.*

## Family TURBINIDAE

### Genus **Argalista**, Iredale, 1915

Type (original designation): *Cyclostrema fluctuata*, Hutton

**Argalista rotella**, n.sp. (Plate L, figs. 18, 19).

Shell small, white, moderately solid, depressed, widely umbilicate. Whorls $3\frac{1}{4}$, including a smooth low convex protoconch of $1\frac{1}{2}$ whorls. Sculpture of post-nuclear whorls consisting of numerous closely spaced, faint, rounded spiral threads, and strong radial folds surrounding the umbilicus. The spiral threads number about forty on the last whorl, and they are slightly more distinct on the upper part. There are thirty axial folds in the holotype and they are strongest where they cross a faintly angular spiral ridge which in turn defines a wide depressed concavity running into the umbilicus. These folds fade out at about half way towards the periphery and also at the umbilicus proper, which is further defined by another angular spiral ridge. Width of umbilicus proper about one-sixth major diameter of base; umbilical concavity almost two-thirds major diameter of base. Aperture circular. Peristome thin, overhanging above and connected across parietal wall by a callous pad. Spire about one-third height of aperture.

Height 1·1 mm.; major diameter 1·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Quite distinct from any of the described species in the strongly developed radial umbilical folds.

**Argalista variecostata**, n.sp. (Plate L, fig. 17).

Shell small, solid, turbinate, umbilicate, sculptured with numerous closely spaced spiral cords, and three spiral keels. Whorls 3½, including minute smooth slightly convex protoconch of one whorl. Spire about two-thirds height of aperture. Umbilicus open, deep, about one-sixth diameter of base, the edge fairly sharp and crenulated by short axial folds. Only two of the spiral keels show on the spire whorls, the third being just below the suture; they are equispaced, rather widely over the middle of the last whorl. The finer spiral cords on the body whorl number nine between the suture and the uppermost keel, followed by eight both between keels 1 and 2 and keels 2 and 3, and finally ten from the lowest keel to the umbilicus. Aperture rounded, typical. Colour of holotype pale pink with very small irregular patches of light brown. Peristome and interior of aperture white. Some paratypes have the ground colour buff.

Height 1·8 mm.; diameter 2·3 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.; also St. 933, 260 m.

This species differs from *fluctuata* (Hutton, 1883) in having the three keels as well as the finer spiral cords. Also it is quite distinct from *crassicostata* (Murdoch, 1905), which is sculptured with a few fairly regular strong spiral cinguli.

Some senile specimens from St. 933 have the three spiral keels much more massive than in the holotype, which represents the normal form.

## Family LEPETIDAE

### Genus **Tectisumen**, Finlay, 1926

Type (original designation): *Cocculina clypidellaeformis*, Suter

**Tectisumen subcompressa**, n.sp. (Plate XLIX, figs. 4, 5).

Shell small, thin, white, oval, somewhat laterally compressed, conical, ends rounded and upcurved. Nucleus a tiny rounded smooth point inclined slightly forwards and situated at about the anterior third. Height almost two-thirds the length; anterior slope straight, posterior slope broadly rounded. There is no sculpture apart from irregular concentric growth lines. Margin sharp and smooth, convex at the sides and slightly concave at the ends. Interior white, smooth, showing horseshoe-shaped muscular impression.

Length 3·1 mm.; breadth 1·9 mm.; height 1·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is most nearly allied to *T. compressa* (Suter, 1908), from which it differs in being not nearly so compressed and in having the nucleus less erect.

**Tectisumen finlayi**, n.sp. (Plate XLIX, figs. 6, 7).

Shell small, thin, white, slightly compressed, conical, ends rounded and slightly upcurved. Nucleus a tiny smooth rounded point, inclined slightly forwards and situated at about the middle. Height about half the length, anterior slope straight, posterior slope slightly convex. There is no sculpture apart from irregular concentric growth lines. Margin sharp and smooth, convex at the sides and slightly concave at the ends. Interior white, smooth, the horseshoe muscular impression clearly shown.

Length 3·7 mm.; breadth 2·45 mm.; height 1·65 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species is allied to both *compressa* and *subcompressa* but differs from them in being very little compressed and in having the nucleus central.

Finlay (1926, *Trans. N.Z. Inst.*, LVII, p. 375) has mentioned the presence of a new species of *Tectisumen* from this area.

## Family FOSSARIDAE

### Genus **Fossarus**, Philippi, 1841

Type (monotypy): *Fossarus adansonii*, Phil., new name for Le Fossar of Adanson = ? *Turbo ambiguus*, L.

**Fossarus aupouria**, n.sp. (Plate XLIX, fig. 12).

Shell small, thin, subglobose, white, keeled and widely umbilicate. Whorls 3½, rapidly increasing and loosely coiled, including a small smooth protoconch of one whorl, obliquely tilted, the apex immersed. Spire a little less than height of aperture. Sculpture consisting of a few equispaced rather sharp-crested prominent spiral keels, three on the spire whorls and eight on the body whorl, the fourth being at the suture and the remaining four on the base, the last one being at the edge of the umbilicus, which is deep and funnel-shaped, varying from about one-sixth to one-seventh the diameter of the shell. The distance from the suture to the first spiral keel is twice that of the intercarinate spaces, resulting in a broad flattened shoulder. There is no axial sculpture apart from faint growth lines. Aperture oblique subcircular. Peristome thin, adnate to parietal wall for a very short space.

Height 1·6 mm.; diameter 1·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species resembles *Fossarus brumalis*, Hedley, 1907 (*Proc. Linn. Soc. N.S.W.*, XXXII, p. 502), from 17 to 20 fathoms off Hope Islands, Queensland.

**Fossarus maoria**, n.sp. (Plate XLIX, figs. 8, 9).

Shell small, thin, auriform, white, keeled and widely umbilicate. Whorls 2½, very rapidly increasing, including a small smooth protoconch of one whorl, obliquely tilted, the apex immersed. Spire less than half height of aperture. Sculpture consisting of a few equispaced rather sharp-crested prominent spiral keels, three on the spire whorl and seven on the body whorl. The lower four keels do not encroach far over the base, the major portion of which is a wide gentle concavity leading to the actual umbilicus which is deep and about one-eighth the diameter of the shell. There is no axial sculpture apart from rather distant and somewhat irregular growth lines which show most prominently in the basal concavity leading to the umbilicus. Aperture oblique, rhomboidal. Peristome thin, discontinuous. Inner lip deeply concave but somewhat flattened medially.

Height 1·5 mm.; diameter 2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This resembles the above species but is much more depressed and widely umbilicate.

## Family RISSOIDAE

### Genus **Haurakia**, Iredale, 1915

Type (original designation): *Rissoa hamiltoni*, Suter, 1898

**Haurakia finlayi**, n.sp. (Plate LII, fig. 1).

Shell small, elongate-conic, white, rather thin and semi-transparent. Whorls five, including a bluntly rounded protoconch of two smooth glossy whorls. Post-nuclear whorls with flatly convex sides and sculptured with regular broad axial plications, about twice their width apart. There are sixteen axials on the penultimate and twenty-one on the body whorl, and they stop suddenly at the periphery of the body whorl where there is a very weak spiral thread which proceeds from immediately above the suture. Base smooth, flattish. Spire about 1½ times height of aperture. Aperture ovate. Peristome continuous across parietal wall, slightly thickened externally. There is no umbilical chink.

Height 2·9 mm.; diameter 1·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Related to the southern New Zealand *H. huttoni* (Suter) rather than to the littoral genotype. In the genotype the axials terminate suddenly at a strong peripheral keel, but in the *huttoni* group (there are a number of undescribed species) the axials diminish but do not abruptly terminate at a very feeble peripheral thread.

**Haurakia aupouria**, n.sp. (Plate LII, fig. 4).

Shell small, ovate-conic, white, moderately strong, shouldered, sculptured with blunt axial costae and broad indistinct spiral cords. Spire gradate, 1½ times height of aperture. Whorls five, including a smooth dome-shaped protoconch of 1½ whorls. Upper third of each whorl occupied by a distinct flattened shoulder, lower two-thirds sculptured with strong vertical bluntly rounded axial costae, seventeen on the last whorl. Suture narrowly canaliculate, margined above and below by distinct spiral cords, the uppermost of which marks the lower extremity of the axials. On the body whorl and base there are five fairly distinct flattened spiral cords, the two margining the suture plus three below, leaving a broad unsculptured zone around the columella. In addition there are six very indistinct spiral cords showing between the interstices of the axials on the last whorl. Aperture ovate, slightly oblique. Peristome continuous across parietal wall, strengthened along the outer lip by a rounded external varix.

Height 2·05 mm.; diameter 1·25 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species stands nearer to the littoral *H. hamiltoni* than to the deeper water and southern *H. huttoni*.

**Haurakia duplicata**, n.sp. (Plate LII, fig. 2).

Shell small, solid, elongate-conic, white. Whorls five, including a blunt dome-shaped protoconch of two smooth whorls. Spire whorls subangled at the middle, base convex, smooth, imperforate. The sculpture consists of a supra-sutural rounded cord which persists right over the last whorl, and strong regular blunt fold-like axials which do not cross the sutural cord. These axials number fourteen on the penultimate and twelve on the last whorl. Spire about 1⅔ height of aperture. Aperture obliquely ovate. Peristome continuous, duplicated on the outside by a heavy rounded varix which leaves the thin slightly dilated inner edge of the outer lip as a projecting rim.

Height 2·85 mm.; diameter 1·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This and the following species differ from all known species of *Haurakia* in the extremely heavy duplicated peristome.

**Haurakia duplicata exuta**, n.subsp. (Plate LII, fig. 3).

The subspecies is almost identical with *duplicata* in shape, the spire whorls differing only in being almost without trace of the subangle, and in having no axial sculpture. Aperture, duplicated peristome, supra-sutural cord, and other characters are as in the typical species.

Height 2·65 mm.; diameter 1·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Genus **Haurakiopsis**, n.gen.

Type: *Haurakiopsis pellucida*, n.sp.

This genus is provided for shells of the general facies of *Haurakia*, having blunt oblique axials, subsidiary spiral sculpture and a sutural thread, but with a distinctly striated protoconch. A second species is Oliver's Kermadec Island *H. kermadecensis* (1915, p. 518). Typical *Haurakia* have a smooth protoconch.

**Haurakiopsis pellucida**, n.sp. (Plate LII, fig. 5).

Shell minute, very thin, translucent, sculptured with distant short blunt oblique axials which do not reach the sutures, and close microscopic spiral striae. Whorls five, including a protoconch of 1½ whorls; tip smooth, remaining whorl sculptured with four fine but distinct spiral striations. The suture is margined above by a narrow thread which extends beyond the aperture and encircles the base. The axials number thirteen on the penultimate and ten on the body whorl. Spire slightly greater than height of aperture. Aperture subcircular. Peristome thin, connected across parietal wall by a light callus. Outer lip slightly sinuous. Basal lip shallowly notched. Columella vertical, slightly arcuate. There is a linear chink between the columella and a broad low fasciolar bulge. Ground colour pale horn, semi-transparent, with the axials standing out in opaque relief.

Height 1·6 mm.; diameter 1·1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 92 m.

This new species superficially resembles *Haurakia hamiltoni* but differs in having a striated protoconch, fewer and shorter axials, and a less prominent sutural ridge.

### Genus **Austronoba**, Powell, 1927

Type (original designation): *Rissoa candidissima*, Webster

**Austronoba iredalei**, n.sp. (Plate LII, fig. 12).

Shell minute, thin, white, semi-transparent, imperforate; sculptured with distant oblique rounded axials and closely spaced spiral lirations. Whorls five, including a typical large dome-shaped protoconch of two smooth whorls. Axial ribs thirteen in number on the penultimate and fifteen on the body whorl; strongly developed on spire whorls but becoming obsolete towards the periphery of the body whorl, and entirely absent from the base. Spiral lirations with linear interspaces, and numbering fifteen on the penultimate and twenty-three on the body whorl and base. There is a moderately wide smooth subsutural band. Spire slightly taller than height of aperture. Outline of whorls strongly convex. Aperture oblique-oval; peristome thin, continuous; outer lip inclined forwards basally and with a broad shallow sinus towards the suture.

Height 2 mm.; diameter 1·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is most nearly allied to the Kermadec Island *A. kermadecensis*, Powell, 1927, but differs in being proportionately wider and in having more numerous spiral lirations.

### Genus **Merelina**, Iredale, 1915

Type (original designation): *Rissoa cheilostoma*, Ten. Woods

**Merelina paupereques**, n.sp. (Plate LII, fig. 10).

Shell small, solid, clathrate, white, rather squat and wide. Whorls $4\frac{3}{4}$, including a typical protoconch of $1\frac{3}{4}$ whorls, sculptured with seven spiral threads. Suture narrowly margined above. Spire whorls with two strong keels, the shoulder relatively much wider than the other interspaces. Body whorl with two more equally strong keels situated upon the upper part of the base, one proceeding from the lower suture. Close in to the columella there are two weak spiral threads. The axials are thin, rather weaker than the spirals and slightly closer in spacing; they become weakly nodulous at the points of intersection with the spirals, and the enclosed rectangular spaces are sharply outlined. The axials barely reach the upper suture and they fall short of the first basal keel. Aperture circular. Peristome continuous, strengthened on the outside by a strong varix.

Height 2·1 mm.; diameter 1·4 mm. (Holotype).

*Habitat:* 60 fathoms off Poor Knights Islands, New Zealand, St. 933 (Holotype). Imperfect specimens from St. 934, 92 m.

Related to the writer's *compacta* (1927, p. 537), having the same squat shape, but larger and with the spiral keels, although the same in number, different in detail and relative spacing.

The writer is indebted to Dr H. J. Finlay for the opportunity of describing this species.

**Merelina manawatawhia**, n.sp. (Plate LII, fig. 8).

Shell small, fragile, white; clathrate, but with the axials slightly stronger than the spirals; rather tall and narrow. Whorls $5\frac{1}{2}$, including typical protoconch of $1\frac{3}{4}$ whorls, sculptured with six spiral threads (worn almost smooth in holotype). Suture narrowly margined above. Spire tall, about twice height of aperture. The post-nuclear sculpture is of strong rounded axials, fourteen per whorl, with interspaces of about four times their width. The spiral cords are narrower and weaker than the axials, which at the points of intersection are rendered angulate and weakly nodulose. On the spire whorls there are three equispaced spiral cords, and on the last whorl, in addition, the sutural cord and three basal ones. The entire surface of the post-nuclear whorls is sculptured with dense spiral striations. Aperture small, oblique-oval, very heavily variced externally. The outline of the whorls is strongly convex, with the periphery above the middle and the sutures deeply indented. On the body whorl the axials rapidly diminish below the periphery and fade out entirely about the uppermost of the basal spirals.

Height 1·75 mm.; diameter 0·98 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Allied to *compacta*, Powell, 1927, but with an additional keel on the spire whorls and differing also in the height.

**Merelina crispulatus**, n.sp. (Plate LII, fig. 7).

Shell small, fairly solid, white; sculptured with prominent flange-like oblique axials and weak intercostal and basal spiral threads. Whorls five, including typical protoconch of 1½ globose whorls, sculptured with seven spiral threads. Spire tall, about 1⅔ height of aperture. The axials, which have the form of very prominent oblique flanges, number twelve on the body whorl. The wide interspaces are sculptured with rounded rather weak spiral cords, three on early whorls, four on penultimate and a total of seven on the body whorl, three of which are on the base. The axials fade out on the base just at the uppermost of the three spirals. The interstitial spiral cords do not cross the axials but they render the profile of the latter faintly angulate. Aperture small, oblique-oval, very heavily variced externally. Whorls strongly convex, high-shouldered and deeply indented at sutures.

Height 1·65 mm.; diameter 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Apparently somewhat allied to the preceding species but differing in having fewer and more widely spaced axials which are developed greatly in excess of the spirals.

**Merelina cochleata**, n.sp. (Plate LII, fig. 6).

Shell small, fairly solid, white; sculptured with a few widely spaced prominent flange-like oblique axials and very weak intercostal and basal spiral threads. Whorls five, including typical protoconch of 1½ globose whorls, sculptured with seven fine spiral threads. Spire tall, about 1⅔ height of aperture. The wide flange-like axials number nine on the body whorl inclusive of the labial varix. The wide interspaces are sculptured with two faint spiral threads and a third which margins the suture above and on the body whorl extends from the top of the labial varix and encircles the base, upon which there are two further spiral threads. The axials fade out just before reaching the base, and the spirals do not cross the axial flanges. Aperture small, oblique-oval, very heavily variced externally. Whorls strongly convex, high-shouldered and deeply indented at sutures.

Height 1·6 mm.; diameter 0·87 mm.

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Closely allied to the preceding species but differing in being more slender and in having fewer axial flanges and spiral cords.

**Merelina crassissima**, n.sp. (Plate LII, fig. 9).

Shell small, squat, very thick and solid, white; sculptured with rather distant heavy axials and moderately strong spiral cords. Whorls four, including globose protoconch of 1½ whorls, sculptured with five strong spiral threads. Spire about 1⅓ times height of aperture. The axials, which are broad and rounded, number eleven on the body whorl, and they do not extend far over the base. Spire whorls with a broad sloping shoulder and two spiral cords which surmount the axials and render them somewhat nodulous.

The suture is margined above by the upper edge of a third cord, which is three parts covered by the succeeding whorl. On the body whorl there are these three spiral cords plus three more on the base, the sixth, which borders the inner lip, being rather indistinct. Aperture small, oblique-oval, very heavily variced externally.

Height 1·5 mm.; diameter 1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species is remarkable for its solidity, squat shape and heavy sculpture.

### Genus **Prumerelina**, Powell, 1926

Type (original designation): *Promerelina crosseaformis*, Powell

**Promerelina tricarinata**, n.sp. (Plate LII, fig. 11).

Shell very small, clathrate, white. Whorls four, including a typical protoconch of $1\frac{1}{2}$ convex whorls sculptured with six minutely granular spiral ridges. Post-nuclear spire whorls with three strong spiral keels, crossed by widely spaced thin axials which become weakly nodulose at points of intersection. Rectangular interspaces much broader than high. Spire tall, about $1\frac{2}{3}$ height of aperture. Whorls deeply indented at suture, and sharply angled at two-thirds their height by the uppermost keel, which is separated from the upper suture by a broad slightly concave shoulder. The axials number twelve on the penultimate whorl. Body whorl with the addition of a single very strong and sharp basal keel which emerges from the suture. Remainder of base smooth and concave except for a strong fold which borders the outside of the inner lip callus, although separated from it by a narrow groove. Aperture oblique-oval. Peristome continuous, externally duplicated by a broad varix.

Height 1·4 mm.; diameter 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This makes the third known species of the genus.

### Genus **Nobolira**, Finlay, 1926

Type (original designation): *Lironoba polyvincta*, Finlay. Lower Miocene, New Zealand

**Nobolira cochlearella**, n.sp. (Plate LII, fig. 15).

Shell small, elongate-conical, thin and fragile; sculptured with narrow spiral ridges. Whorls five, including a large globose protoconch of two whorls which is sculptured with six, regular, fine spiral lirae, and marked off from the post-nuclear whorls by a thin varix. Spire tall, subgradate, about $1\frac{3}{4}$ times height of aperture. Post-nuclear whorls to penultimate with four spiral ridges, increasing to six at the commencement of the body whorl, and with five additional spirals on the base. On the spire whorls the interspaces are twice the width of the ridges, but they are less than their own width on the base. Aperture ovate, oblique. Peristome continuous; outer lip strengthened behind by a slight varix. Colour white, translucent.

Height 1·9 mm.; diameter 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 260 m.

This species is closely allied to *N. finlayi* (Powell, 1930, p. 537) from off Poor Knights Islands in 60 fathoms. The present species, however, differs in having more numerous spiral ridges.

**Nobolira manawatawhia**, n.sp. (Plate LII, fig. 16).

Shell small, ovate-conical, solid, white, sculptured with a few heavy spiral keels. Whorls five, including a typical protoconch of two whorls, sculptured with six fine spiral threads. Spire whorls with two equally strong spiral keels, one just above the middle of the whorl and the other near to the lower suture. There is also an incipient or subobsolete third keel, but even on the last whorl it is hardly noticeable. On the body whorl there is in addition to the two main keels a third one proceeding from the lower suture, and three weaker ones on the base. The surface of the shell is crowded with closely spaced microscopic axial growth striae. Spire gradate, about 1½ times height of aperture. Aperture circular. Peristome continuous, thickened externally by a heavy rounded varix. Parietal callus separated from the body-whorl by a narrow groove.

Height 2·1 mm.; diameter 1·25 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species differs from the previously described New Zealand members of the genus in being proportionately broader.

This Recent species appears to be the direct descendant of the Mid-Pliocene (Nukumaruan) *N. charessa* (Finlay, 1926), differing from it in being slightly broader, and in having only two well-developed keels on the spire whorls and three instead of four on the base.

### Genus **Estea**, Iredale, 1915

Type (original designation): *Rissoa zosterophila*, Webster

**Estea crassicarinata**, n.sp. (Plate LIII, fig. 4).

Shell minute, obtusely conical, solid. Sculptured with heavy spiral keels. Whorls 5½, including a low convex protoconch, not clearly marked off from the post-nuclear whorls. Apex of protoconch smooth, but two spiral keels commence after the first half-whorl and continue over the first post-nuclear whorl, but increase to three on second and four on the penultimate. On the body whorl there are, in addition, three spiral keels on the base. The keels are prominent and rounded, and the interspaces are a little less than the width of these keels. Spire twice height of aperture. Aperture small, almost circular. Peristome continuous, edge thin, neither reflected nor variced, but gradually thickened within. There is no umbilical cavity. Colour buff, tip of spire tinged with reddish brown.

Height 1·5 mm.; diameter 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands. St. 933, 260 m.

In spite of the spiral keels, this species is not a *Lironoba*, for the apertural details are typical of those of *Estea*, which are quite distinctive. Certainly no other *Estea* has such prominent carinate sculpture, but a tendency towards heavy spiral ornament is shown by the New Zealand Pliocene species *E. semisulcata* (Hutton). Furthermore I have recently found *semisulcata* to be a still-living species, occurring in from 6 to 10 fathoms off the Great Barrier Island and off the Little Barrier Island in 20 fathoms.

**Estea porrectoides**, n.sp. (Plate LIII, fig. 1).

Shell small, elongate, subcylindrical, solid and smooth, except for microscopic very irregular axial growth striae. Whorls six, including a low dome-shaped protoconch of 1½ whorls, microscopically sculptured with numerous exceedingly fine and closely spaced punctate spiral striae. Spire tall, about twice height of aperture. Outline of whorls almost straight. Aperture oblique-oval. Peristome continuous, much thickened. There is no umbilical chink. Colour light reddish brown, becoming lighter over body whorl. Peristome and interior of aperture light buff.

Height 2·55 mm.; diameter 1·1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is very near to *E. porrecta*, Powell 1933 (*Rec. Auck. Inst. Mus.*, 1, No. 4, p. 201) from Waitangi, Chatham Islands. The new species differs in having a relatively shorter spire, a larger aperture, more massive peristome, and flatter whorl outlines.

**Estea crassicordata**, n.sp. (Plate LIII, fig. 17).

Shell minute, obtusely conical, very solid, opaque, white. Sculptured with heavy rounded spiral cords having linear interspaces. Whorls 3¾, including a low convex protoconch, similar to that of the preceding species. Apex of protoconch smooth, but four spiral cords commence after the first half-whorl and continue over the first post-nuclear whorl with the addition of an inconspicuous subsutural fifth. Penultimate whorl with five strong cords and a weaker subsutural sixth. Body whorl with the addition of eight basal moderately strong spiral cords. Spire about 1¼ times height of aperture. Aperture small, circular. Peristome continuous, edge thin but much thickened within the aperture. There is no umbilical cavity, but the inner lip callus is much thickened and raised above the base.

Height 0·9 mm.; diameter 0·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This is closely allied to the preceding species, having the same style of protoconch, but differs in having many more spirals and in the shell being smaller and more squat.

**Estea subrufa**, n.sp. (Plate LIII, fig. 2).

Shell small, solid, elongate-conic with a much inflated body whorl but narrowly conical spire with straight sides. Spire 1¾ times height of aperture. Whorls 4½, including a low dome-shaped protoconch of 1½ whorls which is faintly sculptured with about sixteen rows of spiral punctate lines. Post-nuclear whorls smooth except for very faint irregular growth lines. Aperture almost circular. Peristome continuous across parietal wall as a thin callus defined by a ridge at its outer extremity. Outer lip thin at edge but thickened within. Columellar portion of peristome slightly expanded. There is no umbilicus but just a semicircular fold behind the expanded columellar lip. There is a slight basal broad shallow depression which proceeds from the suture in front of the aperture, but it persists for only half a whorl and is not present towards the close of the body whorl. Colour of shell light red-brown fading to white on the latter half of the body whorl and the aperture.

Height 2 mm.; diameter 1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species stands nearest to *E. subfusca* (Hutton, 1873), from which it differs in being constantly smaller, with a proportionately more inflated body whorl, and in having an aperture that is broader than high and the presence of a shallow depression in front of the aperture.

**Estea manawatawhia**, n.sp. (Plate LIII, fig. 3).

Shell large for the genus, very thick and solid and strongly axially costate. Spire twice height of aperture, elongate-conic, sides almost straight. Whorls five, including a dome-shaped protoconch of 1½ whorls, which are faintly sculptured with about sixteen rows of spiral punctate lines. All post-nuclear whorls sculptured with massive axial costae, sixteen on the penultimate and eighteen on the last whorl. Intercostal spaces equal to width of ribs. On the base there is a slight depression extending in front of the aperture from the suture, but as in the preceding species it does not extend over the latter half of the body whorl nor do the axial costae cross the level of this basal depression. Aperture rather small, ovate, slightly higher than wide. Peristome continuous across parietal wall, thin at edge but considerably thickened within. Colour light brown banded with white. On the spire whorls the upper half of the whorl is white and the lower brown, and on the base a second and narrower white band proceeds from the suture.

Height 2·7 mm.; diameter 1·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 932, 933, 185 m.

This species resembles *E. semiplicata*, Powell, 1927, but differs in having more numerous axial ribs which extend over all the post-nuclear whorls.

## Genus **Coenaculum**, Iredale, 1924

Type (original designation): *Scalaria minutula*, Tate and May

**Coenaculum secundum**, n.sp. (Plate LII, fig. 13).

Shell minute, narrow, elongate, cylindrical, white. Whorls 5½, plus a large medially carinate smooth protoconch of 1½ whorls, the tip inrolled. Spire tall, 2¾ times height of aperture. Outline of spire whorls slightly angled just above the middle. Body whorl with a heavy rounded sutural keel. Base flat, imperforate. Post-nuclear sculpture of thin flexuous axials which become almost obsolete on crossing the sutural keel. There are about twenty-two axials on the body whorl. Aperture small, quadrate. Peristome discontinuous, thin, flexuous, sigmoid in profile, a broad deep sinus at the angle and produced forwards below it in an outward curve corresponding to the sinus. Columella short, arcuate. Basal lip thin, straight and horizontal.

Height 1·5 mm.; diameter 0·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This, the second known species of the genus, differs from the Tasmanian genotype in having the upper and lower keels obsolete from the protoconch and only the middle one remaining. The post-nuclear characters, however, are almost identical, the axials being finer and more numerous and the whorls higher.

Iredale (1924, *Proc. Linn. Soc. N.S.W.*, XLIX, p. 244), in proposing the genus, wrote that it was a very peculiar form without any known close relations and certainly not referable to the Rissoidae. However, Iredale does not indicate to which family he considers the species really belongs, so I prefer to leave it in the Rissoidae, particularly as *Coenaculum* appears not very dissimilar from *Awanuia*, a new genus which I proposed in 1927 (*Trans. N.Z. Inst.*, LVII, p. 538) and referred to the vicinity of *Merelina* in the Rissoidae.

### Genus **Manawatawhia**, n.gen.

Type: *Manawatawhia analoga*, n.sp.

This genus resembles *Rissoina* in general features but differs in having a carinate protoconch and a simple, not channelled, basal lip. It is evidently much nearer to *Anabathron*, which has a similar protoconch and apertural features, but different type of sculpture. The simple axials of *Manawatawhia*, without spirals of any sort, are so opposed to the strong spiral keels, plus dense axial foliations of *Anabathron*, that the above-proposed genus is considered necessary for this species alone.

**Manawatawhia analoga**, n.sp. (Plate LII, fig. 14).

Shell minute, fairly solid, white, elongate-cylindrical, sculptured with strong vertical costae. Whorls $5\frac{3}{4}$, plus a comparatively large blunt tricarinate protoconch of $1\frac{3}{4}$ whorls, apex inrolled leaving a tiny apical cavity. Spire tall, $2\frac{1}{3}$ times height of aperture, with outlines evenly and moderately convex. The axial costae number fourteen on the last whorl; they finish at the suture, the base being smooth, and the interspaces are about $1\frac{1}{2}$ times the width of the costae. Aperture D-shaped, the flat parietal side lying at about 45° to the axis of the shell. Outer lip strengthened on the outside by a massive varix. In profile the aperture is inclined forwards basally. Parietal callus long and straight with a slight bulge or fold towards the base of the pillar. Peristome continuous and not channelled.

Height 1·8 mm.; diameter 0·7 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 260 m.

### Genus **Notosetia**, Iredale, 1915

Type (original designation): *Barleeia neozelanica*, Suter

**Notosetia subgradata**, n.sp. (Plate LIII, fig. 10).

Shell very small, ovate, rather thin, white. Whorls $3\frac{3}{4}$, including a relatively large dome-shaped protoconch of $1\frac{1}{2}$ smooth whorls. Spire strongly gradate, a little less than height of aperture. Post-embryonic whorls smooth, but with a rather flat shoulder, the edge of which carinates the whorls. Aperture narrowly oval, almost vertical. Peristome continuous across parietal wall, slightly thickened and expanded, sharp edged. Columella short and arcuate. Umbilical chink narrow and crescentic.

Height 1·5 mm.; diameter 1·1 mm. (Holotype).

Height 1·7 mm.; diameter 1·1 mm. (Topotype of *gradata*).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Related to the Snares Islands' *N. gradata* (Suter, 1908), but more rounded, thinner, without spiral striations, and having a more upright aperture and a shorter spire.

**Notosetia aoteana**, n.sp. (Plate LIII, fig. 11).

Shell minute, ovate-conical, narrowly umbilicate, thin, semi-transparent, white. Whorls four, including a dome-shaped glossy protoconch of 1½ smooth whorls. Spire conical, outlines lightly convex, a little less than height of aperture. Suture impressed, false-margined by the basal part of the preceding whorl showing through. Surface smooth and glossy except for a band of fourteen fine closely spaced spiral striations at the periphery and three rather stronger and wider spaced spiral threads around the umbilical area. Umbilicus very narrow but deep. Aperture rounded. Peristome discontinuous. Outer lip thin and sharp, inclined slightly forwards above. Columella thickened, arcuate, separated from the base by a groove which runs into the umbilicus.

Height 1·2 mm.; diameter 1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Superficially similar to my *Lissotesta benthicola* (Powell, 1927, *Rec. Cant. Mus.*, III, pt. 2, p. 115) which also has a peripheral band of fine striations. It is, however, a true member of the Rissoidae, being related to *Notosetia neozelanica* (Suter), which is similar except that it is larger, imperforate and without the peripheral spirals.

**Notosetia porcellanoides**, n.sp. (Plate LIII, fig. 9).

Shell minute, ovate-conical, thin, smooth, translucent, white. Whorls four, including a small globose protoconch of 1½ smooth whorls, the apex slightly tilted. Spire tall, about 1½ times height of aperture; outlines lightly and evenly convex, nowhere shouldered or flattened. Suture linear, shallow, false-margined below. Aperture ovate, almost vertical. Peristome connected across parietal wall by a heavy callus. Outer lip, basal lip and columella thickened slightly. Umbilical chink narrow, crescentic.

Height 1·35 mm.; diameter 0·88 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is most nearly allied to Suter's *porcellana*, from which it differs in being proportionately smaller, narrower, and without the subsutural shoulder.

**Notosetia subtenuis**, n.sp. (Plate LIII, fig. 8).

Shell minute, ovate-conical, thin, translucent, white, sculptured with exceedingly fine dense spiral striations and equally fine but more distant axial growth lines. Whorls four, including a small bluntly rounded protoconch of 1½ whorls, smooth except for four minute widely and equally spaced striations. Spire conical, about 1¼ times height of aperture, outline of whorls strongly convex. Aperture ovate. Peristome discontinuous, thin. Columella vertical, arcuate, separated from the base by a narrow umbilical chink.

Height 1·2 mm.; diameter 0·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Superficially very close to *N. tenuisculpta* Powell (1933, *Rec. Cant. Mus.*, IV, p. 37) from 170 fathoms off the Bounty Islands, but differing in having more strongly convex whorls, a wider umbilical chink, and the presence of distant microscopic spiral striae upon the protoconch. The nucleus of *Notosetia* is smooth, but otherwise *subtenuis* is quite typical of the genus, and may thus be placed there provisionally.

**Notosetia aupouria**, n.sp. (Plate LIII, fig. 12).

Shell very small, ovate-conical, thin, translucent, colourless. Whorls 5½, including a small smooth dome-shaped protoconch of two smooth whorls. Spire tall, about 1⅓ times height of aperture. Outline of spire whorls lightly convex, body whorl rounded at periphery and on base. Post-embryonic whorls sculptured with very fine spiral striations: fourteen on penultimate whorl increasing to about twenty-four on the body whorl, between the suture and a peripheral thread. The base at first appears to be smooth, but under a higher magnification shows dense exceedingly fine striations. Aperture ovate, angled above. Peristome thin, discontinuous. Columella vertical, straight. No umbilical chink. Basal lip very shallowly and broadly notched.

Height 1·9 mm.; diameter 1·25 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Related to Suter's *infecta* from Lyall Bay and elsewhere in the south, but differing from that species in being proportionately broader and in having dense spiral striae over the whole of the post-nuclear whorls.

## Family RISSOINIDAE

### Genus **Rissoina**, d'Orbigny, 1840

Type (by monotypy): *Rissoina inca*, d'Orbigny. West Coast, South America

**Rissoina aupouria**, n.sp. (Plate LIII, fig. 6).

Shell rather large for the genus, elongate-conic, gracefully tapered. Spire tall, about 1⅔ height of aperture. Whorls eight, including a protoconch of two smooth whorls. Post-nuclear sculpture of closely packed weak axial ribs and microscopic interstitial spiral threads. There are thirty-four axials on the penultimate whorl and they are about their own width apart. The spiral threads are very numerous and closely spaced over the spire whorls, but open out a little over the base. Aperture oblique, ovate, channelled above and below. Peristome continuous, outer lip, basal lip and columella heavily calloused. Colour bright yellowish brown, protoconch and apertural callus white.

Height 8·5 mm.; diameter 3·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 92 m.

The type of sculpture is very like that of Hedley's genus *Stiva* (1904), but the shell is a typical *Rissoina.*

This now becomes the largest member of the genus known from New Zealand waters. It resembles Finlay's *powelli*, but differs in having twice as many axials.

**Rissoina achatinoides**, n.sp. (Plate LIII, fig. 7).

Shell elongate-conic, smooth and glossy. Apart from numerous faint axial growth striae there is neither spiral nor axial sculpture. Whorls six, including a dome-shaped protoconch of two smooth whorls; outlines straight. Spire tall, just twice height of aperture. Aperture oblique, ovate, angled above and distinctly channelled at the base of the columella. Outer lip slightly thickened, almost straight with side of spire. Columella oblique, short and twisted. Colour buff on the apical whorls, deepening to a rich golden brown on the two last whorls. The interior of the aperture is of the same golden brown colour, but the calloused columella is white.

Height 4·8 mm.; diameter 1·8 mm. (Holotype).

*Habitat:* Off Waikuku Beach, near North Cape, St. 930, 29 m.

This is the only New Zealand *Rissoina* so far known that is entirely without both spiral and axial sculpture. It is near to Odhner's *achatina*, but that species has crowded faint spirals and an aperture of the *chathamensis* type. In *achatinoides* the aperture is proportionately rather smaller and has the outer lip in line with the side of the spire.

**Rissoina manawatawhia**, n.sp. (Plate LIII, fig. 5).

Shell small, very tall and slender, glossy and smooth except for very faint, almost obsolete, spiral scratches. Apart from weak, fairly numerous and somewhat irregular axial growth lines there is no true axial sculpture. Whorls six, including a dome-shaped protoconch of two smooth whorls. Outlines slightly convex. Spire tall, about 2¼ times height of aperture. Aperture small, oblique, ovate, angled above and channelled at base of columella. Outer lip thickened, convex. Colour very pale rose pink with an indistinct narrow white spiral zone just above the lower suture.

Height 3·7 mm.; diameter 1·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species is close to Finlay's *fictor*, from 38 fathoms off Cuvier Island, but differs in the practically obsolete spiral sculpture and smaller size. The colour differs also, but in this genus the coloration is so variable that it cannot be taken into account.

The New Zealand Recent species of *Rissoina* are now as follows: (1) *chathamensis* (Hutton, 1873) (= *rugulosa*, Hutton, 1873), (2) *zonata*, Suter, 1909, (3) *rufolactea*, Suter, 1908, (4) *achatina*, Odhner, 1924, (5) *anguina*, Finlay, 1926, (6) *powelli*, Finlay, 1930, (7) *fictor*, Finlay, 1930, (8) *fucosa*, Finlay, 1930, (9) *larochei*, Finlay, 1930, (10) *aupouria*, Powell, 1936, (11) *manawatawhia*, Powell, 1936, (12) *achatinoides*, Powell, 1936.

## Genus Dardanula, Iredale, 1915

(= *Dardania*, Hutton, 1882. Type (by monotypy): *Dardania olivacea*, Hutton). Type (of *Dardanula*) (by subsequent designation, Finlay, 1924): *Dardania olivacea*, Hutton

**Dardanula roseospira**, n.sp. (Plate LIII, fig. 13).

Shell minute, elongate-conical, smooth and polished. Colour light yellowish brown, protoconch light pink, merging gradually over the first post-nuclear whorl into the light brown of the rest of the shell. Spire tall, slightly greater than height of aperture. Outline of whorls lightly convex, body whorl narrowly rounded at periphery, but not angulate. Whorls 4½, including a dome-shaped smooth protoconch of 1½ whorls. Surface smooth, except for very faint but closely spaced axial growth lines. Aperture ovate. Peristome thin and sharp, almost continuous, joined across the base by the parietal callus. There is a slight groove behind the columellar portion of the inner lip, but there is no true umbilicus.

Height 1·4 mm.; diameter 0·95 mm.; (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species differs from its relatives, *roseola*, Iredale, 1915, and *roseocincta*, Suter, 1908, in being proportionately slightly broader and in having different coloration, which is very constant.

**Dardanula tenella**, n.sp. (Plate LIII, fig. 15).

Shell minute, elongate-conical, thin, smooth and polished. Colour translucent buff, with a peripheral series of small squarish opaque white dots alternating with irregular faint blotches of light brown. Also there are a few irregular faint light brown blotches in a spiral series just beneath the suture. Spire tall conical, about 1¾ times height of aperture. Outline of whorls lightly convex, body whorl narrowly rounded at periphery. Whorls 4½, including a smooth dome-shaped protoconch of 1½ whorls. Aperture ovate. Peristome thin and sharp, connected across parietal wall by a well-defined callus. Columellar portion straight and vertical. There is no umbilicus.

Height 2·1 mm.; diameter 1·3 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

Apart from the tenuity of the shell the type of aperture and style of shell are in strict accord with *Dardanula*. It recalls *Cithna*, but lacks the slightly emarginate base of that genus.

**Dardanula pallida**, n.sp. (Plate LIII, fig. 16).

Shell minute, elongate-conical, thin, smooth and polished. Whorls 4½, including a smooth dome-shaped protoconch of 1½ whorls. Spire tall, conical, straight in outline, 1¾ times height of aperture. Body whorl subangulate at periphery. Colour very pale pinkish buff, interior of aperture white. Aperture and peristome typical. Imperforate.

Height 1·65 mm.; diameter 1·05 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is very similar to the littoral *D. olivacea lutea* (Suter, 1908) but is much smaller, has a thinner shell and is much lighter in colour.

**Dardanula minutula**, n.sp. (Plate LIII, fig. 14).

Shell minute, bluntly elongate-conical, pupoid, thin but not fragile, smooth and polished. Whorls 4½, plus a broad low dome-shaped protoconch of about 1½ whorls. Spire tall, bluntly conical, 1¾ times height of aperture. Outline of whorls very slightly convex, body whorl rounded at periphery, base convex, smooth, imperforate. Aperture small, roundly ovate. Peristome thin, continuous as a callus across the parietal wall. Lower portion of inner lip sharp edged, free, slightly overhanging the base. The suture is inclined steeply downwards to the aperture just before the termination of the last whorl.

Height 0·95 mm.; diameter 0·55 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is characterized by its extremely small size, small aperture and blunt apex. In shape it resembles some of the species that have been ascribed to *Notosetia*, but the form of the aperture is typical of *Dardanula*.

## Family CERITHIIDAE

### Genus **Zebittium**, Finlay, 1926

Type (original designation): *Cerithium exilis*, Hutton

**Zebittium laevicordatum**, n.sp. (Plate LIV, fig. 3).

Shell small, elongate, narrow, gently tapered; sculptured with delicate smooth low spiral cords, having linear interspaces. Whorls 7½, including a smooth dome-shaped protoconch of 1½ whorls; tip slightly tilted and immersed. First and second post-nuclear whorls showing very indistinct spiral striations. Third post-nuclear whorl with eight low flattened smooth cords separated by linear interspaces; succeeding spire whorls with nine, body whorl with six more on base. There is no axial sculpture and there are only the finest growth striae. Spire tall, a little less than three times height of aperture. Outlines almost straight, suture very slightly adpressed. Aperture ovate-pyriform, narrow above, broadly rounded below, and with a broad shallow basal notch. Outer lip thin. Inner lip as a moderately heavy narrow arcuate callus extending from the suture right to the base of the pillar. Colour pale creamy buff with a few small widely spaced buff-coloured spots. These occur only on the first subsutural cord and on the basal ones.

Height 4·05 mm.; diameter 1·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from its allies, *exile* (Hutton, 1873) (*Cat. Marine Mollusca*, p. 27) and *editum*, Powell, 1930 (*Trans. N.Z. Inst.*, LX, p. 541), in the complete absence of axial sculpture.

### Genus **Zaclys**, Finlay, 1926

Type (original designation): *Cerithiopsis sarissa*, Murdoch

**Zaclys paradoxa**, n.sp. (Plate LIV, fig. 1).

Shell small, elongate-conical, tumid below, but tapering to a sharp point above. Whorls nine, including a tall slender polygyrate protoconch of four whorls. Surface of protoconch worn, but remains of the typical daphnellid reticulation and terminal carina are distinguishable. Spire tall about $4\frac{1}{2}$ times height of aperture. Outline of spire convex below and slightly concave above towards protoconch. Post-nuclear sculpture of two spiral rows of very strong laterally compressed oval gemmules, about fourteen per whorl. On the base there are two smooth strong spiral cords, one proceeding from immediately below the suture and the other situated below towards the neck. Aperture broken in all available specimens.

Height 2·1 mm.; diameter 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

Differs from other species of the genus in having only two rows of strong gemmules. There is a deceptive resemblance to Hedley's *Joculator*, but that genus has a smooth polygyrate protoconch.

### Genus **Mendax**, Finlay, 1926

Type (original designation): *Cerithiopsis trizonalis*, Odhner

**Mendax attenuatispira**, n.sp. (Plate LIV, fig. 5).

Shell small, narrow, attenuated, with almost straight outlines. Whorls sixteen plus a cylindrical protoconch of three whorls; tip smooth, then sculptured with closely spaced arcuate axial ribs. Post-nuclear whorls bicarinate, the lower carina slightly the more prominent; both sculptured with rectangular nodules numbering about eighteen per whorl. Suture margined above by a weak spiral thread. Spire about seven times height of aperture. Base smooth. Aperture squarish with a short oblique partly restricted recurved canal. Outer lip recurrent towards suture, where there is a rather deep sinus. Colour pale buff.

Height 5·4 mm.; diameter 1·3 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Genus **Paramendax**, n.gen.

Type *Paramendax apicina*, n.sp.

This genus is proposed for the species described below, which although superficially similar to *Mendax*, has a very distinctive protoconch, the first whorl being small and bead-like and the next two very much wider and sculptured with wide-spaced strong axials.

**Paramendax apicina**, n.sp. (Plate LIV, fig. 4).

Shell small, tall and narrow, many whorled with a curious gradate apex of about three whorls, not clearly marked off from the post-nuclear whorls. Tip of protoconch small, smooth, bead-like, followed by two rapidly spreading whorls that are sculptured with rather wide-spaced strong axials. Adult sculpture of two rounded wide-spaced spiral ridges which are crowded with strong squarish nodules, about twenty per whorl. Sutures not deep, lower one having immediately above it a thin axial thread. Aperture quadrate terminating below in a short open canal. End of columella strongly flexed to the left. Outer lip thin and sharp. Colour pale buff.

Height 5·4 mm.; diameter 1·45 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Genus **Socienna**, Finlay, 1926

Type (original designation): *Cerithiopsis apicicostata*, May

**Socienna elegantula** (Powell, 1930).

1930 *Altispecula elegantula*, Powell, *Trans. N.Z. Inst.*, LX, p. 539.

The genus *Altispecula* was proposed by the writer (*loc. cit.*, 1930, p. 539) for a South Australian deep-water shell which had strong axial ribs, only obsolete spiral sculpture and a protoconch of two smooth convex whorls. The species *elegantula* was referred to this genus, as the post-nuclear sculpture was somewhat similar and what little of the damaged protoconch that remained seemed to be smooth. However, it now appears that the apex must have been worn, for perfect examples from the dredgings of the 'Discovery II' (St. 933) show a tall and narrow protoconch of three whorls, the top bluntly rounded, all but the first whorl sculptured with regularly spaced thin axial ribs, having interstices of about three times the width of the ribs. The first whorl of the protoconch is sculptured with microscopic closely spaced spiral series of granules and the next two have a pair of fine peripheral threads. The protoconch is closely similar to that of my *Seilarex exaltatus* (*loc. cit.*, 1930, p. 538), a species considered by Finlay (1930, *Trans. N.Z. Inst.*, LXI, p. 230) to be better placed in his *Socienna*. I have since described another *Socienna* with predominant axials, in my *S. aureola* (1933, *Rec. Cant. Mus.*, IV, p. 38).

## Family TRIPHORIDAE

### Genus **Notosinister**, Finlay, 1926

Type (original designation): *Triphora fascelina*, Suter

**Notosinister aupouria**, n.sp. (Plate LIV, fig. 2).

Shell small, slender, rather fragile. Whorls fourteen, including a typical polygyrate protoconch of five whorls, having a sharp median carina crossed by closely spaced fine axial threads. Spire tall, a little more than five times height of aperture. Outline very slightly convex, lower part of spire cylindrical but gradually tapered above to the sharp pointed protoconch. Upper six post-nuclear whorls with two keels; succeeding four whorls with the addition of a third subsidiary keel between the two main keels; these are crossed by slightly oblique axial riblets which are raised into moderately strong rounded gemmules at the points of intersection with the keels. On the body whorl there is the addition of a smooth sutural keel and two more below it on the base. Aperture oval, vertical, having a deep narrow sutural notch and produced below into a short almost closed tube-like canal, slightly bent to the right. Peristome thin and sharp, outer lip in profile straight with axis of shell medially, but strongly recurrent at sutural notch. Ground colour of shell pale buff, with protoconch, upper and lower keels but not the subsidiary third keel marked out in light brown. Base from below the smooth sutural keel, including the canal, coloured uniformly light brown, slightly darker than that of the protoconch and keels of the spire.

Height 4·3 mm.; diameter 1·3 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is nearly allied to *N. infelix* (Webster, 1906), but differs from that species, which is plain white, in being banded with light brown. Also, *infelix* is more slender, has the three gemmulate spirals equally developed over the later whorls, the base with a weaker pair of spirals, and an oval aperture with an almost closed canal, more as in *ampulla*, Hedley, 1902.

## Family VERMETIDAE

### Genus **Vermicularia**, Lamarck, 1799

Type (monotypy): *Serpula lumbricalis*, Linn.

**Vermicularia maoriana**, n.sp. (Plate LV, figs. 9, 10).

Shell small, solitary, spirally coiled; nuclear whorls attached to some foreign object, succeeding whorls regularly coiled but sinistral, adherent to each other as in a normal conical trochoid. The aperture has a flange-like continuous peristome from which emerges a loose, detached, irregularly spiral tube. The position of the peristome at an earlier stage is shown by a varix at the close of the penultimate and in line with the present one; the tube also bears a similar terminal flange. The surface is smooth but with traces of obsolete axial folds. Umbilicus deep, about one-third width of base. Colour dull white.

Height 2·4 mm.; diameter 1·1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This is not a typical *Vermicularia*, but it is placed here provisionally pending a revision of the Austral members of the family.

## Family LAROCHEIDAE

### Genus **Larochea**, Finlay, 1927

Type (by monotypy): *Larochea miranda*, Finlay

**Larochea secunda**, n.sp. (Plate L, fig. 7).

Shell minute, thin, fragile, dull white, globose, wide-mouthed and few-whorled, resembling a diminutive *Lamellaria*. Whorls three, including a smooth planorbid apex of one whorl. Post-nuclear sculpture of dense microscopic spiral striae, crossed by regular closely spaced axial growth lines. Aperture oval, extremely large, occupying more than two-thirds the base. Outer lip thin and sharp. Inner lip sinuous, kinked at about half the height of the aperture and from there broadly spreading, the outer edge forming the parietal callus margin and the inner the broad spiral columella. Internal crepidulid-like shelf set deeply within the aperture. Spire about one-third height of aperture.

Height 0·9 mm.; diameter 0·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This is the second species of the genus, and it differs from the genotype in being much more globose, and in having a less twisted columella and a taller spire.

## Family AMPHIPERATIDAE

### Genus **Pedicularia**, Swainson, 1840

Type (by monotypy): *Pedicularia sicula*, Swainson

**Pedicularia maoria**, n.sp. (Plate LIV, figs. 13, 14).

Shell small, ovate, but no doubt variable in outline according to the shape of the organism upon which it is commensal. Sculptured with about sixty-six fine, rounded, spiral threads, with interspaces of equal width, or varying to 1½ times the width of the threads. The whole is crossed by fairly numerous flexuous concentric growth ridges. Apical whorls bluntly conical, immersed upon the underside by the body whorl. The tip is smooth, low, dome-shaped, and the remaining spire whorls (approximately two) are sculptured with about six closely spaced spiral ridges which are cut up into square granules by deeply incised axial grooves. Aperture oblong, extremities broadly notched, peristome entire, thin; inner lip as a raised attenuated callus, which is spirally ridged on the outside, the ridges being considerably coarser than, and often slightly oblique to the normal spiral sculpture of the body whorl; outer lip thin, similarly raised. Columella expanded medially, slightly convex, without denticles but with a distinct anterior notch. Posteriorly the columella is bordered by a weak canal. Colour uniformly pale buff.

Length 4·9 mm.; breadth 2·5 mm.; thickness 1·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

The only specimens are empty shells, so the nature of the host is unknown. Judging by the compressed aperture of the shell the host is in all probability a branching bryozoan of small diameter.

This adds a genus and family to the New Zealand fauna. The Australian species, *P. stylasteris*, Hedley, 1903, from off Wollongong, in 49–50 fathoms, New South Wales, differs from the New Zealand species in having a denticulate columella and an apex almost completely buried.

## Family EPITONIIDAE

### Genus **Aclis**, Loven, 1846

Type: *Aclis supranitida*, Wood

**Aclis maoria**, n.sp. (Plate LVI, fig. 12).

Shell very small, turreted, elongate, white, sculptured with sharp spiral keels. Whorls 7½, including a globular smooth protoconch of two whorls. Spire about three times height of aperture. Spire whorls with two prominent keels, increasing to three by the penultimate. There is a fairly prominent supra-sutural spiral as well, and this almost equals the strength of the keels on the body whorl. The base is smooth, almost flat, and is separated from a deep crescentic umbilical cavity by a sharp ridge. Aperture quadrate. Peristome discontinuous. Outer lip thin and sharp. Pillar arcuate and slightly reflected over the umbilicus.

Height 3·4 mm.; diameter 1·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Allied species are Hutton's *Turritella* (*Eglisia*) *planostoma* (1885, *Trans. N.Z. Inst.*, XVII, p. 320) from the Pliocene of Wanganui and my *terebra* (1930, *Trans. N.Z. Inst.*, LX, p. 538) which I incorrectly ascribed to *Icuncula*.

## Family ARCHITECTONICIDAE

### Genus **Zerotula**, Finlay, 1926

Type (original designation): *Discohelix hedleyi*, Mestayer

**Zerotula triangulata**, n.sp. (Plate LIV, figs. 15, 16).

Shell minute, discoidal, thin, semi-transparent, glossy, spire and base concave; surface smooth except for faint somewhat irregular axial growth lines. There are three moderately strong spiral keels which render angulate the otherwise almost uniformly convex whorls. The keels are equidistant in spacing, the middle one at the periphery, the other two on the spire and the base respectively midway between periphery and suture. Whorls 2¾, protoconch minute, smooth, inrolled. Aperture circular. Peristome thin, continuous, adnate to parietal callus for a very short space. The latter half of the body whorl inclines slightly upwards, which results in the concave spire being slightly deeper than the corresponding umbilical cavity.

Height 0·55 mm.; major diameter 1·1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from the genotype in having the whorls circular, not squarish, in section. Both species have somewhat similar tricarinate sculpture.

**Zerotula crenulata**, n.sp. (Plate LIV, figs. 6, 7).

Shell minute, discoidal, moderately solid, opaque, white, spire and base slightly concave; surface dull, sculptured with numerous rounded radial threads, having inter spaces varying from two to four times the width of the threads. Whorls $2\frac{3}{4}$, protoconch minute, smooth, inrolled. Outline of whorls bicarinate, flattened above and below but lightly convex between the carinations. Carinations as moderately strong rounded cords which are crenulated by the traversing of the radials. Aperture squarish. Peristome thin, continuous, retractive towards parietal wall.

Height 0·4 mm.; major diameter 1·1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species closely resembles *bicarinata* (Suter, 1908) in shape, but instead of being smooth it has close radial sculpture, which crenulates the keels.

## Family PYRAMIDELLIDAE

### Genus **Eulimella**, Jeffreys, 1847

**Eulimella aupouria**, n.sp. (Plate LIV, fig. 9).

Shell minute, subulate, smooth and polished, semi-transparent white, imperforate. Whorls six, plus a heterostrophe protoconch of two convex smooth whorls. Spire about $3\frac{1}{2}$ times height of aperture; outline of whorls very lightly convex, slightly flattened in the middle. Suture lightly impressed, false-margined below. Aperture narrowly ovate, peristome simple, outer lip thin but somewhat thickened at the columella.

Height 2·25 mm.; diameter 0·58 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This and the next species have been separated as new by Dr C. R. Laws who has prepared a monograph of the New Zealand pyramidellids.

### Genus **Chemnitzia**, d'Orbigny, 1893

Type (*fide* Dall and Bartsch): *Turbonilla inaspectus*, Fuchs

**Chemnitzia lawsi**, n.sp. (Plate LIV, fig. 8).

Shell minute, subulate, semi-transparent, polished, white, imperforate. Whorls $6\frac{1}{2}$, plus a heterostrophe protoconch of two whorls, the apex being tilted and almost immersed by the first post-nuclear whorl. Spire tall, about $3\frac{1}{2}$ times height of aperture; outline of whorls lightly convex. Post-nuclear sculpture of strong regularly spaced rounded axials with excavated interspaces equal to the ribs in width and terminating just above the suture, the base being smooth. The axials number about sixteen per whorl. Aperture narrowly ovate; peristome thin and sharp, nowhere thickened.

Height 2·35 mm.; diameter 0·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

### Family EULIMIDAE

### Genus Balcis, Leach, 1847

(=*Eulima*, Auct.)
Type (Winckworth, 1934): *Balcis montagui*=*B. alba* (da Costa)

**Balcis bollonsi**, n.sp. (Plate LIV, figs. 11, 12).

Shell small, smooth, white, very slender, tapering to a small globular protoconch, not clearly marked from later whorls. Whorls seven. Spire 2½ times height of aperture, outline of whorls perfectly straight; suture barely distinguishable. The spire has a fairly considerable double or spiral twist. Aperture narrowly pyriform. Outer lip thin and slightly retractive towards suture.

Height 2·8 mm.; diameter 0·7 mm.

*Habitat:* North of the North Cape, New Zealand, in 75 fathoms (dredged by the late Captain J. Bollons).

*Holotype:* In writer's collection, Auckland Museum.

**Balcis aupouria**, n.sp. (Plate LIV, fig. 10).

Shell small, smooth, translucent, white, highly polished, allied to the last species but not nearly so slender, nor is the spire so twisted. Whorls seven, including a rather blunt dome-shaped protoconch. Aperture narrowly pyriform. Outer lip strongly convex medially, in profile.

Height 3·75 mm.; diameter 1·2 mm.

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Family MITRIDAE

### Genus Egestas, Finlay, 1926

Type (original designation): *Vexillum waitei*, Suter

**Egestas dissimilis**, n.sp. (Plate LV, fig. 8).

Shell small, moderately solid, ovoid-biconic, white; spire a little less than height of aperture. Whorls 3½, including a large dome-shaped smooth protoconch of 1½ whorls, the tip tilted and immersed. Sculpture of numerous weak axial folds and subobsolete fine spiral threads, about eight of which can be seen with difficulty on and immediately above the fasciole and neck. The axials number about twenty-two on the last whorl. Aperture small, narrow. Outer lip thin, sharp and evenly arcuate. Canal open, very short and weakly notched. Parietal wall not excavated, bearing medially three strong oblique plaits. Fasciole very weakly defined.

Height 2·8 mm.; diameter 1·45 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species is not a typical *Egestas* but may be placed here provisionally for want of a better location. It agrees with the genus in having three columellar plaits, and the protoconch is similar, but the style of sculpture and short canal are not typical.

### Genus **Peculator**, Iredale, 1924

Type (original designation): *Peculator verconis*, Iredale, 1924

**Peculator coma** (Odhner, 1924).

1924. *Marginella coma*, Odhner. *N.Z. Mollusca*, Papers from Mortensen's Pacific Exped. 1914–1916, No. 19, p. 42.
1926. *Peculator* ("distantly related to") *coma*, Odhner. Finlay, *Trans. N.Z. Inst.*, LVII, p. 434.

Odhner's type came from 10 miles north-west of Cape Maria van Diemen. Identical specimens were taken at Sts. 929, 931 and 932. Dead shells are pure white as the holotype, but fresh material shows a coloration of orange-brown with irregular laterally elongate splashes of light buff.

A closely allied species is *Mitra hedleyi*, Murdoch, 1905. This shell agrees with *coma* in the details of protoconch, sculpture and even coloration, the main difference between the two being the much narrower proportions of *hedleyi*.

## Family PYRENIDAE

### Genus **Zemitrella**, Finlay, 1926

Type (original designation): *Lachesis sulcata*, Hutton

**Zemitrella sericea**, n.sp. (Plate LVI, fig. 3).

Shell small, elongate subcylindrical, thin, pale buff; protoconch, first post-nuclear whorl and base unevenly stained with light brown. Surface silky in appearance, caused by exceedingly fine, dense and regular, axial growth striae on a microscopically pitted surface, the minute punctures being arranged in dense regular spiral series. Whorls five, including a papillate protoconch of 1½ whorls, the tip slightly oblique and the whole surface covered with the microscopic punctate-striae. Spire tall, about 1¼ times height of aperture. Whorls evenly and lightly convex. Body whorl subcylindrical. Aperture narrow, slightly channelled above and narrowly notched below. Outer lip thickened medially but thin at extreme edge. Pillar straight medially, but deeply concave over parietal wall and sloping obliquely to left below. A weak plait borders this inner edge of the base of the pillar. The neck or lower part of the base is sculptured with seven fairly distinct oblique rounded spiral cords with linear interspaces. The uppermost of these cords is strongest and the lowest almost obsolete.

Height 3·5 mm.; diameter 1·45 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

Quite distinct from any of the described species in its silky surface.

**Zemitrella annectens**, n.sp. (Plate LVI, fig. 4).

Shell small, elongate-fusiform, thin, white. Surface silky, caused by exceedingly fine and dense axial growth striae, similar to that of the previous species except that the axial striae are still finer and there is no spiral series of punctate-striae. Spire tall, a little greater than height of aperture. Whorls four, including a smooth papillate protoconch of 1½ whorls, the tip slightly oblique. Whorls evenly and lightly convex. Aperture long and narrow with parallel sides, channelled above and very shallowly notched below. Outer lip straight medially and slightly thickened back from the edge, which is thin. Pillar straight medially, very little oblique below and bordered by the characteristic weak plait at the base. Body whorl slender, lightly convex, very slightly constricted towards the neck which bears nine rather broad, low, rounded, weak, oblique cords with linear interspaces.

Height 3·1 mm.; diameter 1·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, Sts. 933, 934, 92 m.

Allied to the previous species but differing from it in being more fusiform, less tightly coiled, not so much constricted towards the neck and in having a smaller protoconch. Also the axial sculpture is weaker and there are no punctate spiral striae.

**Zemitrella turgida**, n.sp. (Plate LVI, fig. 5).

Shell small, very solid, ovate-biconic. Whorls 5¼, including a bluntly rounded smooth protoconch of 1½ whorls, the nucleus slightly oblique. Spire about equal to height of aperture plus canal. Whorls gently convex, sutures not much impressed. There is no sculpture apart from seven flat spiral cords with linear interspaces situated on the neck of the base. Aperture narrow with parallel sides, slightly angled and weakly notched above, open but neither notched nor recurved below. Outer lip fairly thin at edge but much thickened just within the aperture, where there is a row of about six (base of outer lip slightly damaged in holotype) distinct denticles. Columella vertical medially but very slightly curved to the left below. Ground colour pale buff, with three rows of white chevrons, which are marked out with light brown on their front edge. Protoconch and sculptured part of the neck also white. The spire whorls have only the one band of chevrons, the largest. The other two chevron bands are very narrow; one occurs just below the junction of the outer lip with the body whorl and the other just at the uppermost of the spiral cords on the neck.

Height 4·3 mm.; diameter 2·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species appears to be nearest to *Z. stephanophora* (Suter, 1908), so far as can be judged from the holotype which is a badly beach-worn shell. Well-preserved specimens, assumed to be *stephanophora*, differ from the Three Kings Islands shell in being larger and more elongate, and in having a smooth slightly dilated outer lip and a papillate protoconch.

**Zemitrella curvirostris**, n.sp. (Plate LVI, fig. 6).

Shell small, ovate-elongate. Whorls five, including a papillate smooth protoconch of 1½ whorls, with the nucleus slightly tilted. Spire a little greater than height of aperture plus canal. Whorls gently rounded, sutures lightly impressed. Surface practically smooth, rendered slightly silky by extremely fine and crowded axial growth striae. The only true sculpture is thirteen flattened spiral cords with linear interspaces which are situated on the neck of the base. Aperture moderate, with parallel sides, slightly angled and weakly notched above and produced below into an open, short, slightly recurved canal which is broadly notched at its extremity. Outer lip rather straight medially, thin at edge but thickened both externally and internally just back from the edge. There are no denticles on the inside of the outer lip. Columella vertical medially and having a slight ridge of callus bordering its edge. Ground colour pale buff, with protoconch, basal sculptured neck and aperture white. There is also a broad central band of irregularly shaped white blotches and small haphazard blotches of light brown.

Height 3·9 mm.; diameter 1·9 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species also is allied to *stephanophora*, differing in narrow build and longer recurved canal. From *turgida* it differs in shape, and the absence of denticles inside the outer lip.

### Genus **Antimitrella**, n.gen.

Type: *Antimitrella laxa*, n.sp.

This genus is necessary for the species described below, which although evidently related to *Zemitrella*, differs in having a finely axially striated protoconch, no spiral cords on the neck of the canal, and loose rapidly increasing coiling with a downward sag, the whole shell thus remaining narrow and approximately cylindrical. Also the basal notch is broader and weaker than in *Zemitrella*. A point of resemblance to *Zemitrella* is in the moderately strong oblique plait at the base of the pillar.

**Antimitrella laxa**, n.sp. (Plate LVI, fig. 7).

Shell small elongate-cylindrical, thin, white. Whorls $3\frac{1}{2}$, very rapidly increasing and loosely coiled, with a pronounced downward sag. The protoconch is large, almost bulbous, and is sculptured with very fine and closely packed axial striations. Post-nuclear whorls smooth except for faint irregular axial growth lines. Spire about same height as aperture, outline of whorls very lightly convex. Body whorl comprising three-fourths the height of the shell. Aperture long and narrow. Outer lip vertical, very little thickened. Inner lip spread as a weak callus. Pillar bordered below by a moderately strong oblique plait. Anterior canal broad, very shallowly notched. Neck of canal not constricted and without spiral cords.

Height 2·2 mm.; diameter 0·75 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Genus **Liratilia**, Finlay, 1926

Type (original designation): *Daphnella conquisita*, Suter

**Liratilia sinuata**, n.sp. (Plate LVI, fig. 2).

Shell small, moderately solid. Spire tall, $1\frac{1}{2}$ times height of aperture. Whorls sharply angled just above the middle, six in number, including a conical smooth protoconch of two whorls. Sculpture consisting of prominently raised rounded spiral cords, the one at the angle sinuous, regularly produced into vertically compressed nodules. On the spire whorls there are five spiral cords with equal interspaces and on the base nine cords plus seven on the neck of the canal. There are nine nodulous expansions of the peripheral carina on the penultimate whorl. Interspaces crossed by very fine axial growth threads. Aperture long and narrow, sides parallel, angled above and weakly notched below. Outer lip thickened within, bearing four apertural tubercles, the uppermost of which is by far the strongest. Inner lip as a well defined callus. Colour pale buff, sparingly streaked with irregular patches of light brown.

Height 6·2 mm.; diameter 2·6 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

**Liratilia elegantula**, n.sp. (Plate LVI, fig. 1).

Shell small thin, elongate, fusiform. Spire tall, 1½ times height of aperture. Whorls five, including a typical conical smooth protoconch of two whorls. Outline of spire whorls lightly convex, except for a slight concavity immediately below the suture. Body whorl narrow, slightly flattened medially, concave below suture and also towards fasciole. Sculpture consisting of five rather deeply incised lines leaving broad flat spiral bands which number nine on the spire whorls and twenty-one on the body whorl and base, plus nine on the fasciole. The upper four spirals on the concave portion below the suture are narrower than the rest. Aperture long and narrow, sides parallel, weakly notched below. Outer lip thin, not much thickened within, and without tubercles. Colour pure white, sparsely marked with square light brown patches, situated on the fourth and fifth spirals from the suture.

Height 4·6 mm.; diameter 1·75 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

## Family MARGINELLIDAE

### Genus **Marginella**, Lamarck, 1799

Type (by monotypy): *Voluta glabella*, Linn.

### Subgenus **Glabella**, Swainson, 1840

Type (by monotypy): *Voluta faba*, Linn.

**Marginella (Glabella) aupouria**, n.sp. (Plate LV, fig. 5).

Shell small, very solid, white, glossy, ovate-biconic. Spire very low and broadly conic, inflated over upper portion of body whorl and tapering rapidly towards base. Height of spire only about one-tenth height of aperture. Whorls three, including broadly rounded low smooth protoconch of one whorl. Aperture long and narrow, with parallel sides, deeply channelled above and broadly but shallowly notched below. Outer lip straight, thickened by a heavy smooth varix. Columella with four equidistant oblique plaits.

Height 4·3 mm.; diameter 3·05 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species stands nearest to *M. pygmaea*, Sowerby, but differs in having a much shorter and more obtuse spire, and a body whorl that is much inflated above but tapers considerably below.

**Marginella (Glabella) manawatawhia**, n.sp. (Plate LV, fig. 4).

Shell small, solid, dull white, smooth volutiform. Spire about one-third height of aperture, rather sharply conic. Body whorl inflated above and considerably tapered below. Whorls four, including a comparatively small smooth low dome-shaped protoconch of one whorl. Aperture long and narrow, with parallel sides, deeply notched above and broadly but shallowly notched below. Outer lip straight, thickened by a heavy smooth varix which is finely denticulate along its inner margin. Columella with four equidistant oblique plaits.

Height 5·9 mm.; diameter 3·2 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species also resembles *pygmaea* but has a slightly higher spire, more tapered body whorl, parallel-sided aperture, and distinct denticles along the inside of the outer lip.

**Marginella (Glabella) pygmaeiformis**, n.sp. (Plate LV, fig. 3).

Shell small, solid, white, glossy, volutiform. Spire about one-sixth height of aperture. Whorls three, including a small dome-shaped smooth protoconch of one whorl. Aperture long and narrow with parallel sides, channelled above and broadly but shallowly notched below. Outer lip straight, thickened by a heavy smooth varix which is finely denticulate along its inner margin. The labial callus spreads above right to the suture. Columella with four equidistant oblique plaits.

Height 4·8 mm.; diameter 3 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This species has a similar spire and the general proportions of *pygmaea*, but differs in having a more narrowly tapered base and parallel-sided aperture with denticles along its inner edge, as in the preceding species.

### Subgenus **Serrata**, Jousseaume, 1875

Type (by tautonomy): *Marginella serrata*, Gaskoin

**Marginella (Serrata) subamoena**, n.sp. (Plate LV, fig. 6).

Shell small, white, glossy, broadly ovate-biconic. Spire broadly and bluntly conical, less than half height of aperture. Whorls 3½ including broad flattened dome-shaped protoconch of about one whorl. Body whorl tumid above but tapered rapidly below to almost the size of the protoconch. Aperture long, rather narrow with subparallel sides, slightly channelled both above and below but not notched. Outer lip smooth, slightly thickened, broadly arcuate. Columella with four equidistant oblique plaits.

Height 3·8 mm.; diameter 2·5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 932, 185 m.

This species stands nearest to *amoena*, Suter, 1908, from which it differs in being much more tumid and in having a smooth inner edge to the outer lip.

**Marginella angasi**, Crosse, 1870.

*Habitat:* Off Three Kings Islands, St. 933, 260 m. and St. 934, 92 m.

This adds a species to the New Zealand fauna. Specimens are inseparable from New South Wales examples and identical with the excellent figure given by Hedley (1915, *Proc. Linn. Soc. N.S.W.*, XXXIX, p. 726, pl. 82, fig. 66).

### Genus **Closia**, Gray, 1857

Type (monotypy): *Marginella sarda*, Kiener

**Closia maoria**, n.sp. (Plate LV, fig. 1).

Shell of moderate size, ovoid, smooth and polished, white. Spire involute, covered by the calloused end of the labial varix. Columella with four strong plaits. The last whorl occupies the whole height of the shell. Aperture high and narrow, very slightly emarginate below but without a distinct notch. Labial varix heavy, smooth.

Height 7 mm.; diameter 5 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species differs from *C. profunda*, Suter (1909, *Rec. Cant. Mus.*, I, no. 2, p. 128) (see Plate LV, fig. 2) in being larger, more massive, more inflated above and tapered basally, and also in having stronger plaits.

## Family TURRIDAE

### Genus **Nepotilla**, Hedley, 1918

Type (original designation): *Daphnella bathytoma*, Verco

**Nepotilla finlayi**, n.sp. (Plate LVI, fig. 8).

Shell minute, fusiform, thin, turreted, uniformly light brown. Sculpture consisting of spaced strong rounded spiral cords crossed by equispaced thin axial lamellae. Whorls 4, including a typical disproportionately large loosely coiled protoconch of 1½ whorls with flattened sides, sculptured with about fourteen spiral lines. Spire whorls with three strong spiral cords, the lowest margining the suture; base with an additional eight cords, which diminish in strength below, the last three being close together on the fasciole. Post-nuclear whorls crossed by spaced thin lamellar axials which become spinose at the points of intersection with the spiral cords. These axials number eleven on the penultimate and twelve on the body whorl and they fade out over the lower part of the base. Spire about equal to height of aperture plus canal. Aperture rather narrow, sides parallel medially, having an extremely deep sutural sinus and a short open canal inclined to the left and slightly recurved.

Height 2·2 mm.; diameter 1·4 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This adds a genus to the New Zealand fauna. Finlay (1926, *Trans. N.Z. Inst.*, LVI, p. 254) mentioned the presence of undescribed species of *Nepotilla* in New Zealand waters. The genus is strongly represented in Tasmanian and Southern Australian waters.

### Genus **Stilla**, Finlay, 1926

Type (original designation): *Mangilia flexicostata*, Suter

**Stilla paucicostata**, n.sp. (Plate LVI, fig. 11).

Shell close to that of *flexicostata* but proportionately wider and with fewer and stronger axial ribs. Spire of same height as aperture plus canal. Post-nuclear sculpture of strong blunt oblique wide-spaced axials and a few weak spiral cords. On the body whorl there are thirteen axials, compared with eighteen in *flexicostata*. The spiral cords number two on the spire whorls and three on the last whorl, the lowest proceeding from the suture. The axials become faint at the sutural cord and rapidly fade out over the base. Protoconch, sinus and other characteristics as in the typical species.

Height 1·7 mm.; diameter 0·95 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

### Genus **Mitrithara**, Hedley, 1922

Type (original designation): *Columbella alba*, Petterd

**Mitrithara granulifera**, n.sp. (Plate LVI, fig. 9).

Shell rather small, white, solid, biconic. Whorls four, including a smooth rounded protoconch of 1½ whorls. Spire a little less than height of aperture. Outline of whorls lightly convex, base straight, tapering but not concave. Post-nuclear whorls sculptured with the characteristic close revolving cords, which are granulated by axial threads. The spiral cords number seven on the spire whorls and thirty on the body whorl and base, becoming much more closely spaced over the fasciolar portion. Aperture long and narrow, sides parallel medially. Canal wide and short. Sinus broad and shallow, situated just below the suture. Columella straight with two closely spaced weak medially situated plications. Outer lip thin at edge, becoming thicker within the aperture but not variced.

Height 3·85 mm.; diameter 1·8 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species appears to be more closely related to Australian species such as the genotype and *proles*, Hedley, 1922, than to *gemmata* (Suter, 1908) from southern New Zealand.

**Mitrithara regis**, n.sp. (Plate LVI, fig. 10).

Shell rather small, ovate, solid, white, spirally grooved and axially costate. Whorls 4½. Spire about two-thirds height of aperture. Protoconch smooth, dome-shaped, of 1½ whorls, followed by a brephic stage of closely spaced axials. First post-nuclear whorl with four flattened spiral cords with linear interstices, penultimate with five. Body whorl with nineteen spiral cords, six of which are on the fasciole; these being narrower. All post-nuclear whorls crossed by moderately strong axial folds, eighteen per whorl, which become obsolete over the base. Aperture narrow, with parallel sides, and a broad open canal below. Outer lip thin, not variced. Inner lip defined as a fairly broad slightly sunken glaze. Columella with two rudimentary plaits.

Height 5·6 mm.; diameter 3·1 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species resembles *Mitrithara proles*, Hedley (1922, *Rec. Aust. Mus.*, XIII, No. 6, p. 236) from 80 fathoms off Narrabeen, New South Wales.

## Family RETUSIDAE

### Genus **Retusa**, Brown, 1827

Type (*fide* Iredale, 1915 and Woodring, 1928): *Bulla obtusa*, Montagu (= ? *plicata*, Brown = ? *discors*, Brown = ? *Voluta alba*, Kanmacher)

**Retusa aupouria**, n.sp. (Plate LV, fig. 7).

Shell small, ovate-cylindrical, thin, smooth, semi-transparent, glossy, white. Spire deeply sunken, the outer edge of the concavity being defined by a sharp rim. Sides broadly and evenly convex, the last whorl forming the entire height of the shell. Aperture as high as the shell, very narrow above, but broadened out below owing to the contraction of the inner lip towards the columella. Inner lip spread as a thin callus over the parietal wall. Columella short, vertical, thickened, with a slight medial twist.

Height 5·6 mm.; diameter 2·8 mm.

Height 5·1 mm.; diameter 2·65 mm. (Holotype).

*Habitat:* Off Three Kings Islands, St. 933, 260 m.

This species appears to be closely allied to Watson's *Utriculus* (*Tornatina*) *pachys* (*Challenger Rep.*, *Zool.*, XV, p. 660, pl. 49, fig. 8) but is considerably less inflated. Watson's species has the dimensions: height 5·75 mm., diameter 3·5 mm., compared with height 5·6 mm., diameter 2·8 mm. for the shell from Three Kings Islands. *Tornatina murdochi*, Suter, 1915 (= *Cylichna simplex*, Murd. and Suter, 1906), from 110 fathoms off the Great Barrier Island, is still more cylindrical, has the sunken spire concavity smaller, and faint spiral sculpture.

# Class AMPHINEURA

## Family LEPIDOPLEURIDAE

### Genus **Parachiton**, Thiele, 1909

Type (by monotypy): *Lepidopleurus* (*Parachiton*) *acuminatus*, Thiele

**Parachiton textilis**, n.sp. (Plate XLVIII, figs. 4, 5, 6).

Median valves narrow, not beaked, round-backed and high arched, lateral areas very slightly raised; the sculpture of fine, regular quincuncial punctation, central areas with crowded delicately granulate fine closely spaced longitudinal lirae which curve inward slightly at the dorsal ridge, a few short lirae being intercalated above to fill the space occasioned by this slight crowding. There are about 100 of the longitudinal lirae across the whole of a valve, those towards the sides becoming oblique. Posterior valve large and long, almost as long as wide; mucro very close to the lower margin; ante-mucronal area extremely large, triangular, rounded, low-arched and sculptured similarly to the central areas of the median valve, longitudinal lirae totalling about seventy across the valve. Post-mucronal area radially quincuncially lirate. Insertion plates absent, sutural laminae small. Colour uniformly pale buff.

Length 2·5 mm.; breadth 7·5 mm.; height 3·5 mm. median valve (Paratype).

Length 2·5 mm.; breadth 3·8 mm.; height 1·3 mm. posterior valve (Holotype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This is the second New Zealand *Parachiton* to be described, the other (*P. subantarcticus*, Iredale and Hull, 1930, *Aust. Zool.*, VI, pt. 2, p. 157) being from 95 fathoms off the Auckland Islands. The Auckland Island species is based on a single median valve which differs from that of the Three Kings Islands shell in having the longitudinal sculpture coarser and in the form of chains of pustules. Iredale and Hull (1929, *loc. cit.*, pt. 1, p. 30) state that an undescribed species of *Parachiton* was dredged off the north of New Zealand by Scott's Antarctic Expedition.

Although no complete examples of the above new species are available there are sufficient valves to furnish an adequate description of the species.

## Family CRYPTOCONCHIDAE

### Genus **Notoplax**, H. Adams, 1861

Type (by monotypy): *Cryptoplax* (*Notoplax*) *speciosa*, H. Adams

**Notoplax aupouria**, n.sp. (Plate XLVIII, fig. 1).

Median valves very narrow, tegmentum triangular, higher than broad. Sutural laminae wide, sinus narrow, slits one on each side, weak. Dorsal area smooth, narrow, sharply raised, sides almost parallel throughout. Sculpture of prominent raised oval pustules arranged in eleven vertical rows on each lateral area. A weak diagonal fold traverses the lower part of the valve, commencing at the umbo and terminating at the sutural slits. Colour of tegmentum pinkish buff, sutural lamellae white.

Length (tegmentum) 3·6 mm.; breadth (tegmentum) 3·5 mm.; maximum breadth 5·3 mm.; height 2·5 mm. (Holotype, one median valve).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This is a very distinctive species, most nearly allied to the Southern Australian-Tasmanian *speciosa*, the genotype. No complete examples were taken.

**Notoplax websteri**, n.sp. (Plate XLVIII, figs. 2, 3).

Median valves rather broad, tegmentum much broader than high. Sutural laminae not very wide, sinus broad. Dorsal area broadly wedge-shaped and strongly beaked.

Sculpture of ovate to almost triangulate pustules arranged in diagonal and longitudinal rows. There are thirteen longitudinal rows on each side of the dorsal area and the innermost ones merge into folds along the sides of that area. The surface of the dorsal area is sculptured with irregular longitudinal incised lines and pittings. A weak diagonal fold traverses the lower part of the valve, commencing at the umbo and terminating at the sutural slits. Colour of tegmentum in the holotype pale pink at sides, variegated light brown and green medially, and pale buff with faint brownish longitudinal lines on the dorsal area. Tail valve small, tegmentum broadly-ovate. Dorsal area broadly wedge-shaped, mucro at lower third of height. Sculptured with six longitudinal rows of prominent ovate to triangulate pustules. Sutural laminae, dorsal area and most of the pustules pale buff to white, ground colour between pustules on lateral areas light brown mottled with green.

Length (tegmentum) 4 mm.; breadth (tegmentum) 5 mm.; maximum breadth 5·4 mm.; height 2·5 mm. (Holotype, one median valve).

Length (tegmentum) 1·5 mm.; breadth (tegmentum) 1·9 mm.; maximum breadth 2·6 mm.; height 1·3 mm. (Paratype).

*Habitat:* Off Three Kings Islands, St. 934, 92 m.

This is a benthic species allied to the littoral and shallower-water *mariae* (Webster, 1908). The new species differs in having a much wider sinus, more broadly wedge-shaped dorsal area, and distinctive sculptural details, the pustules being more openly spaced and the dorsal area with deeply incised lines and pittings reminiscent of *Craspedochiton*.

# PLATE XLV

Fig. 1. *Aupouria parvula*, n.gen. et sp. (Holotype). 1·6 × 1·5 mm.

Fig. 2. *Dimya maoria*, n.sp. (Holotype). 6·1 × 7·7 mm.

Fig. 3. *Cratis delicatula*, n.sp. (Holotype). 2·4 × 3 mm.

Fig. 4. *Cratis retiaria*, n.sp. (Holotype). 2·5 × 3 mm.

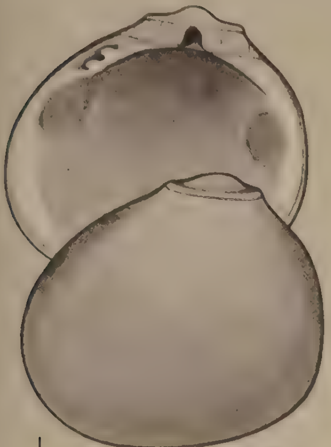
Fig. 5. *Pleuromeris latiuscula*, n.sp. (Holotype). 2·2 × 2·2 mm.

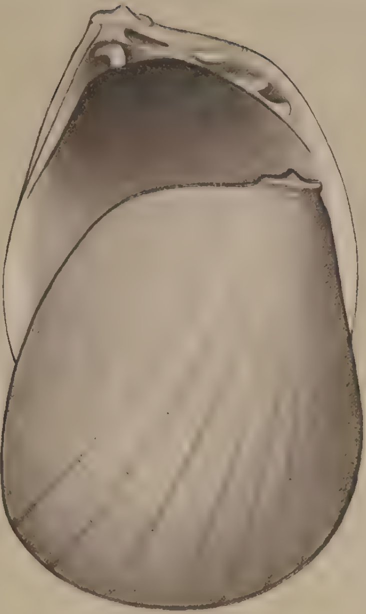
Fig. 6. *Pleuromeris latiuscula benthicola*, n.subsp. (Holotype). 2·6 × 2·3 mm.

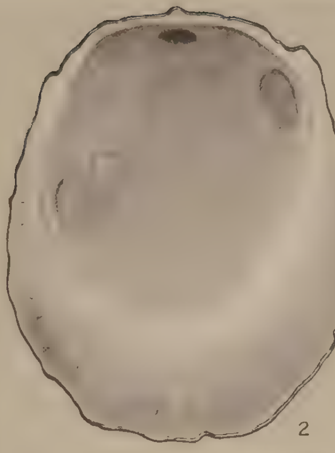
Fig. 7. *Cosa serratocostata dispar*, n.subsp. (Holotype). 2·2 × 2·1 mm.

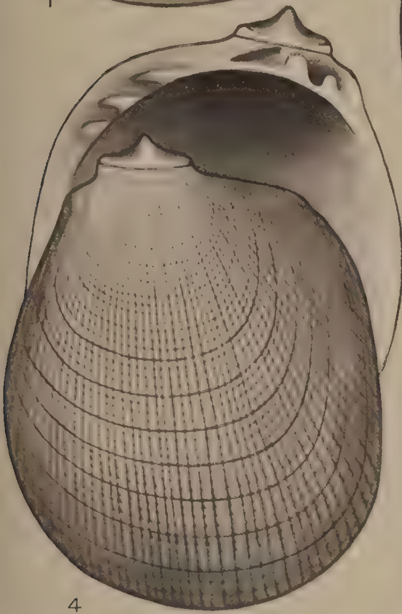
Fig. 8. *Pronucula maoria*, n.sp. (Holotype). 1·8 × 1·5 mm.

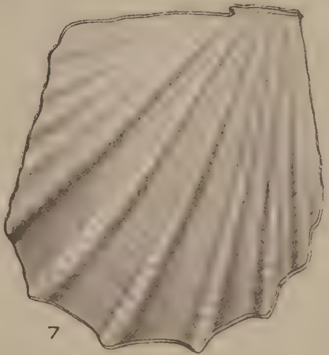
Fig. 9. *Nuculana (Jupiteria) manawatawhia*, n.sp. (Holotype). 4·2 × 2·9 mm.

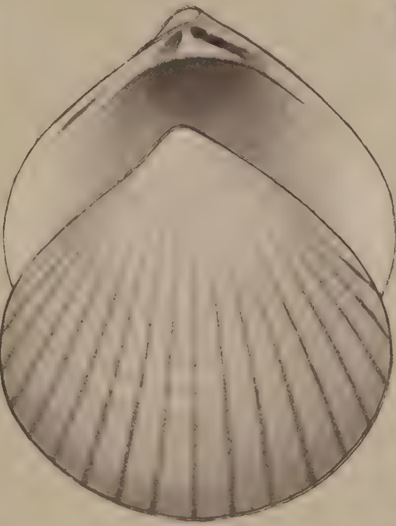

1

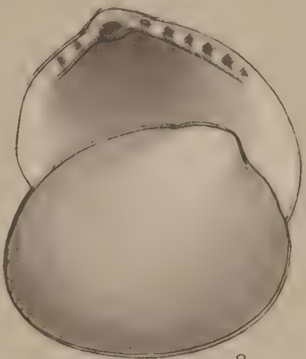

3

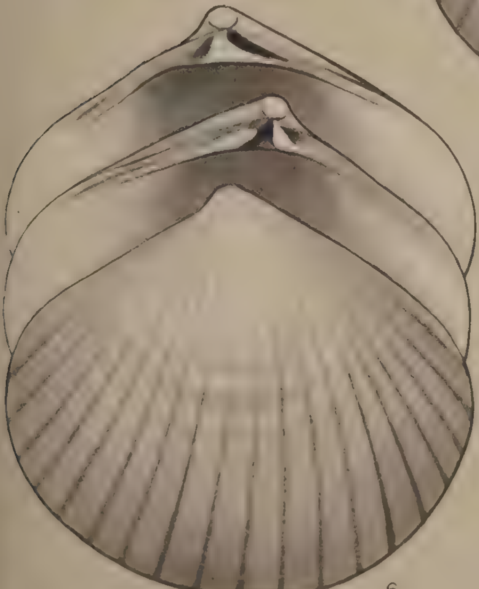

2

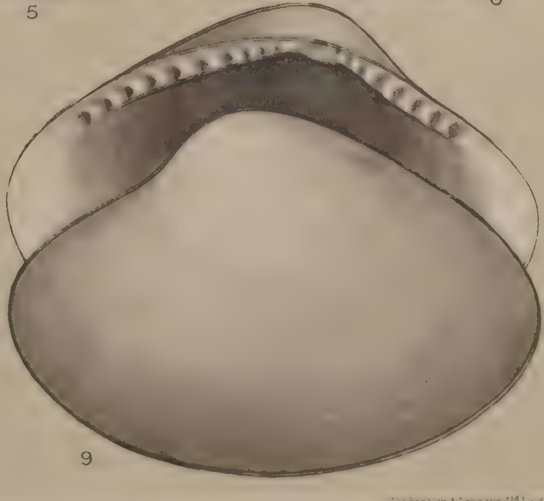

4


7


5


8


6


9

A W B P del.

John Bale Sons & Danielsson, Ltd London

MOLLUSCA FROM NEW ZEALAND

## PLATE XLVI

Figs. 1 and 2. *Cuna aupouria*, n.sp. (Holotype). 2·1 × 2·3 mm.

Fig. 3. *Cuna waikukuensis*, n.sp. (Holotype). 1·7 × 1·9 mm.

Fig. 4. *Cuna gibbosa*, n.sp. (Holotype). 2·00 × 2·25 mm.

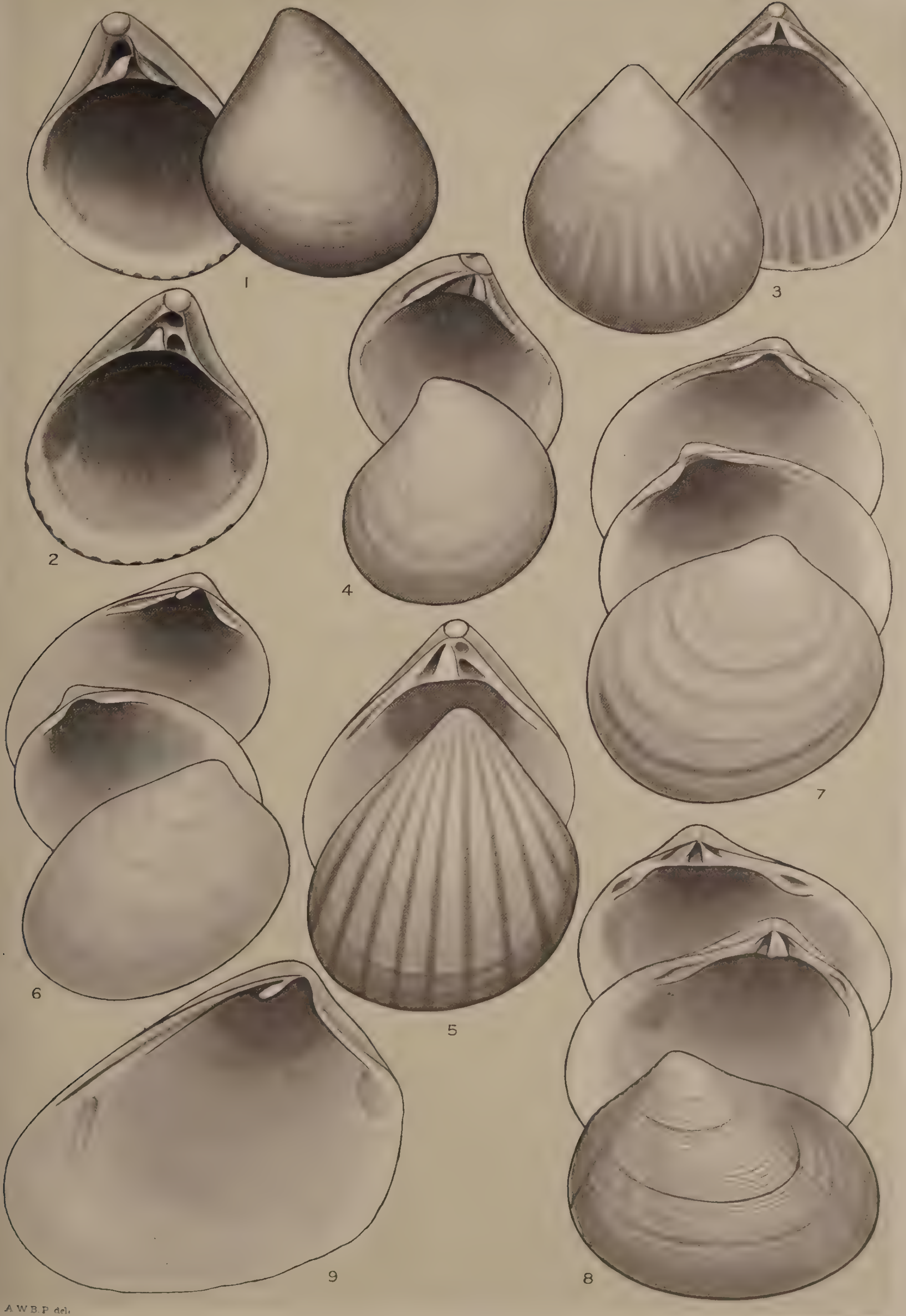
Fig. 5. *Cuna manawatawhia*, n.sp. (Holotype). 2·6 × 2·9 mm.

Fig. 6. *Mysella alpha*, n.sp. (Holotype). 2·15 × 1·6 mm.

Fig. 7. *Mysella beta*, n.sp. (Holotype). 3·3 × 2·8 mm.

Fig. 8. *Epicodakia neozelanica*, n.sp. (Holotype). 5·5 × 4·2 mm.

Fig. 9. *Parvithracia cuneata*, n.sp. (Holotype). 5·2 × 3·7 mm.



A W B P del.

MOLLUSCA FROM NEW ZEALAND

# PLATE XLVII

Fig. 1. *Cyclopecten* (*Cyclochlamys*) *aupouria*, n.sp. (right valve).

Fig. 2. *Cyclopecten* (*Cyclochlamys*) *aupouria*, n.sp. (Holotype) (left valve). 3·4 × 2·9 mm.

Fig. 3. *Cyclopecten* (*Cyclochlamys*) *secundus*, Finlay, 1926 (right valve).

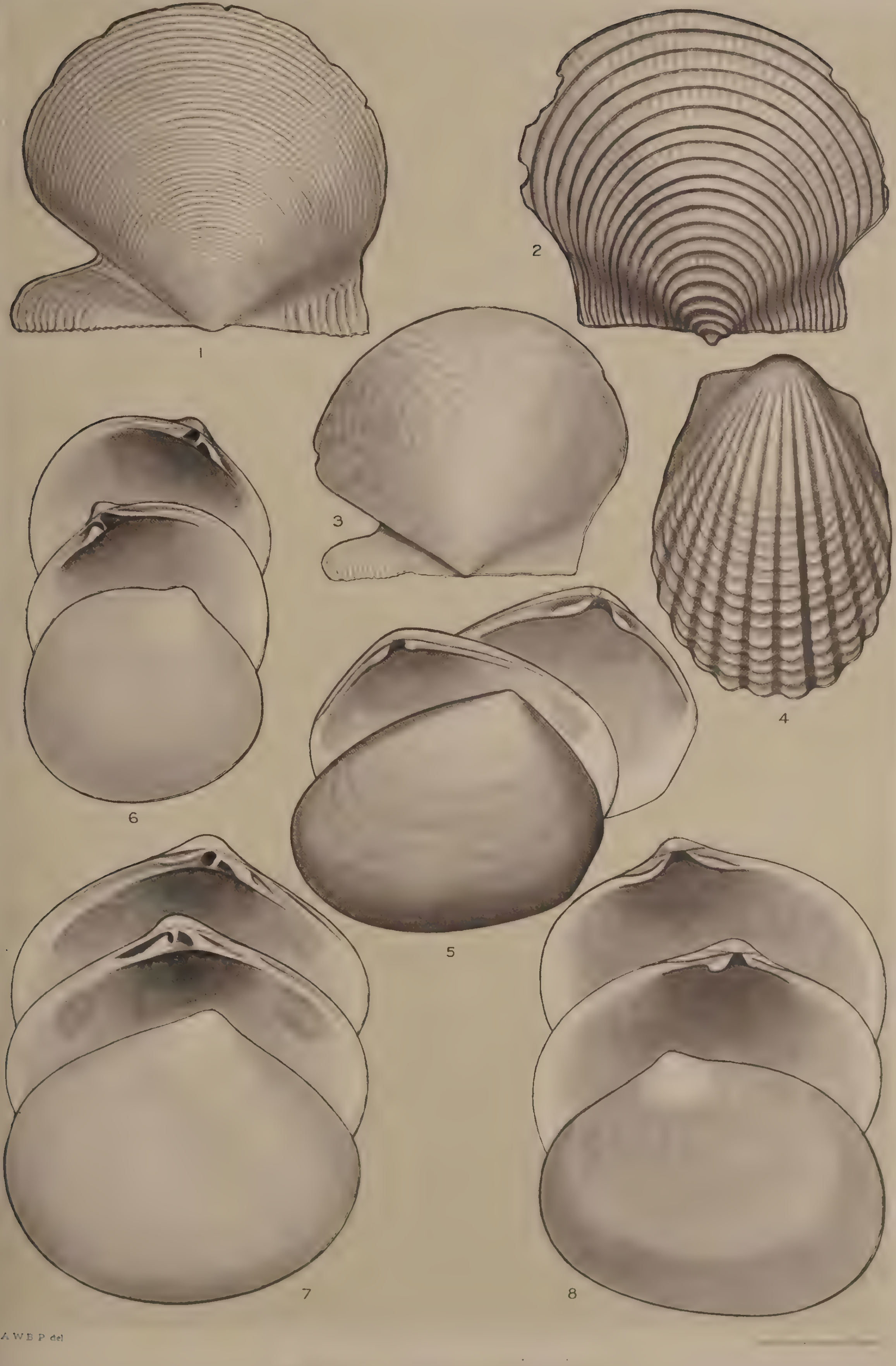
Fig. 4. *Limatula aupouria*, n.sp. (Holotype). 1·6 × 2·4 mm.

Fig. 5. *Mysella aupouria*, n.sp. (Holotype). 3·5 × 2·7 mm.

Fig. 6. *Notolepton subobliquum*, n.sp. (Holotype). 2·08 × 1·85 mm.

Fig. 7. *Notolepton sublaevigatum*, n.sp. (Holotype). 2·8 × 2·3 mm.

Fig. 8. *Borniola neozelanica*, n.sp. (Holotype). 4·55 × 3·3 mm.



A W B P del

MOLLUSCA FROM NEW ZEALAND

# PLATE XLVIII

Fig. 1. *Notoplax aupouria,* n.sp. (Holotype). 3·6 × 3·5 mm.

Fig. 2. *Notoplax websteri,* n.sp. (Holotype) median valve. 4 × 5 mm.

Fig. 3. *Notoplax websteri,* n.sp. posterior valve.

Fig. 4. *Parachiton textilis,* n.sp. (Paratype) median valve. 2·5 × 7·5 mm.

Fig. 5. *Parachiton textilis,* n.sp. (Paratype) median valve.

Fig. 6. *Parachiton textilis,* n.sp. (Holotype) posterior valve. 2·5 × 3·8 mm.

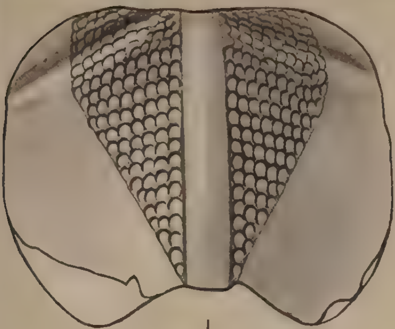
Figs. 7 and 8. *Puncturella manawatawhia,* n.sp. (Holotype). 1·5 × 1·15 mm.

Fig. 9. *Zeidora maoria,* n.sp. (Holotype). 2·9 × 1·4 mm.

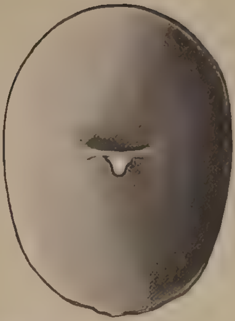
Fig. 10. *Zeidora maoria,* n.sp. (Paratype).

Fig. 11. *Austroneaera brevirostris,* n.gen. et sp. (Holotype). 4·4 × 2·9 mm.

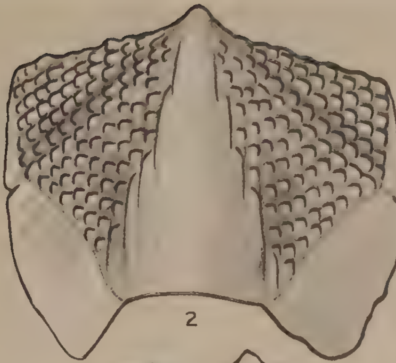
Fig. 12. *Austroneaera finlayi,* n.sp. (Holotype). 3·5 mm. × 2·5 mm.



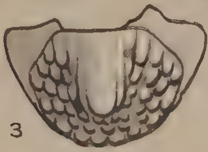
1



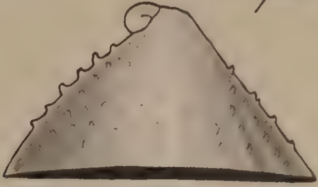
7



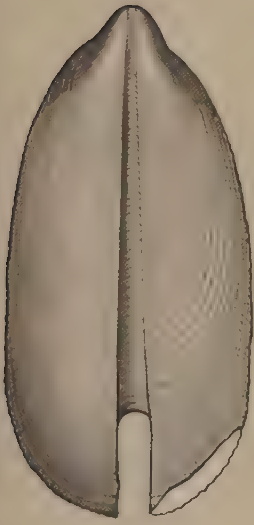
2



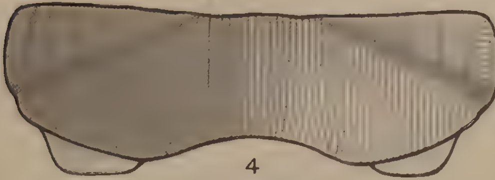
3



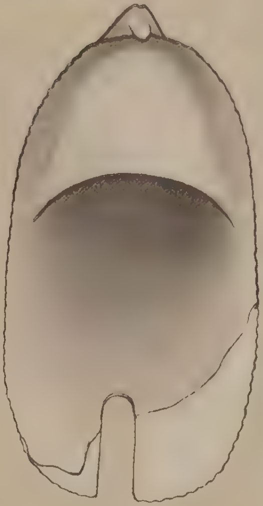
8



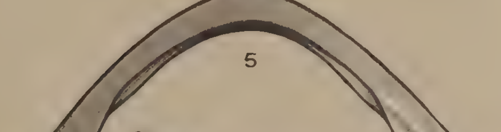
9



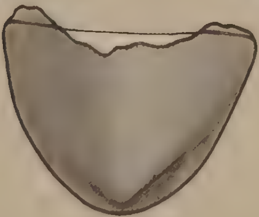
4



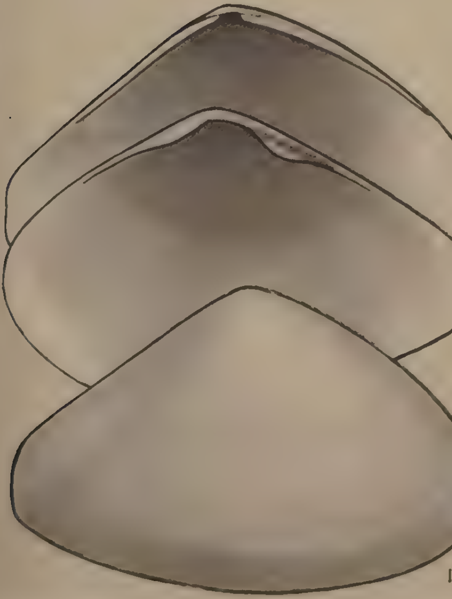
10



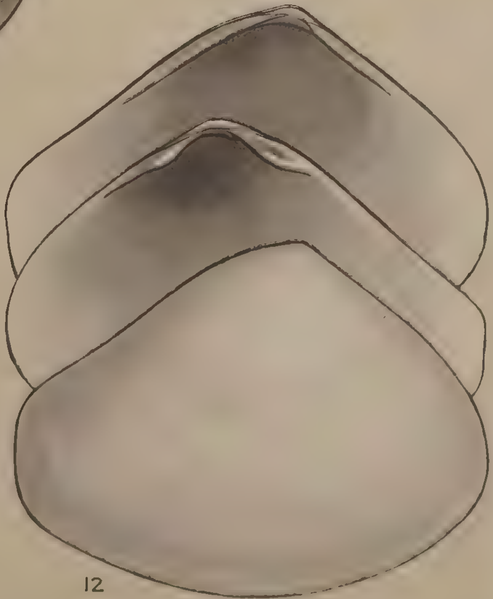
5



6



11



12

A W B P del.

John Bale Sons & Danielsson, Ltd London

MOLLUSCA FROM NEW ZEALAND

# PLATE XLIX

Fig. 1. *Scissurella manawatawhia*, n.sp. (Holotype). 1·05 × 1·0 mm.

Fig. 2. *Schizotrochus finlayi*, n.sp. (Holotype). 1·7 × 1·9 mm.

Fig. 3. *Schizotrochus aupouria*, n.sp. (Holotype). 0·9 × 1·25 mm.

Figs. 4, 5. *Tectisumen subcompressa*, n.sp. (Holotype). 3·1 × 1·9 × 1·8 mm.

Figs. 6, 7. *Tectisumen finlayi*, n.sp. (Holotype). 3·7 × 2·45 × 1·65 mm.

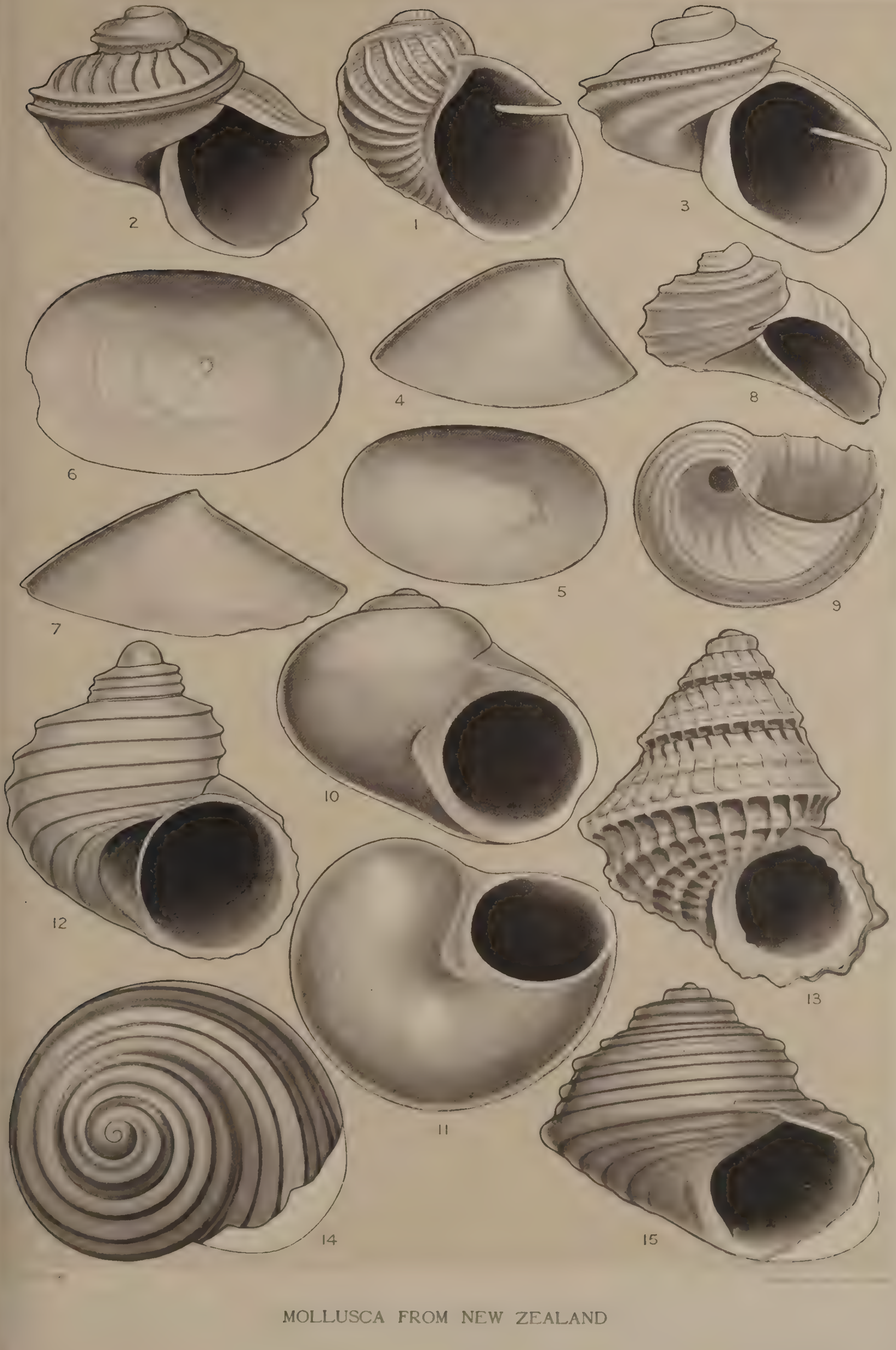
Figs. 8, 9. *Fossarus maoria*, n.sp. (Holotype). 1·5 × 2 mm.

Figs. 10, 11. *Starkeyna maoria*, n.sp. (Holotype). 1·3 × 1·7 mm.

Fig. 12. *Fossarus aupouria*, n.sp. (Holotype). 1·6 × 1·5 mm.

Fig. 13. *Herpetopoma benthicola*, n.sp. (Holotype). 3·5 × 3 mm.

Figs. 14, 15. *Thoristella crassicosta*, n.sp. (Holotype). 3·7 × 4·5 mm.


2
1
3
4
8
6
5
9
7
12
10
13
11
14
15

MOLLUSCA FROM NEW ZEALAND

# PLATE L

Figs. 1, 2. *Munditia manawatawhia*, n.sp. (Holotype). 0·8 × 1·5 mm.

Figs. 3; 4. *Munditia aupouria*, n.sp. (Holotype). 1·7 × 3·5 mm.

Figs. 5, 6. *Munditia echinata*, n.sp. (Holotype). 0·6 × 1·4 mm.

Fig. 7. *Larochea secunda*, n.sp. (Holotype). 0·9 × 0·9 mm.

Figs. 8, 9. *Cirsonella laxa*, n.sp. (Holotype). 0·8 × 1·25 mm.

Figs. 10, 11. *Cirsonella waikukuensis*, n.sp. (Holotype). 0·7 × 0·9 mm.

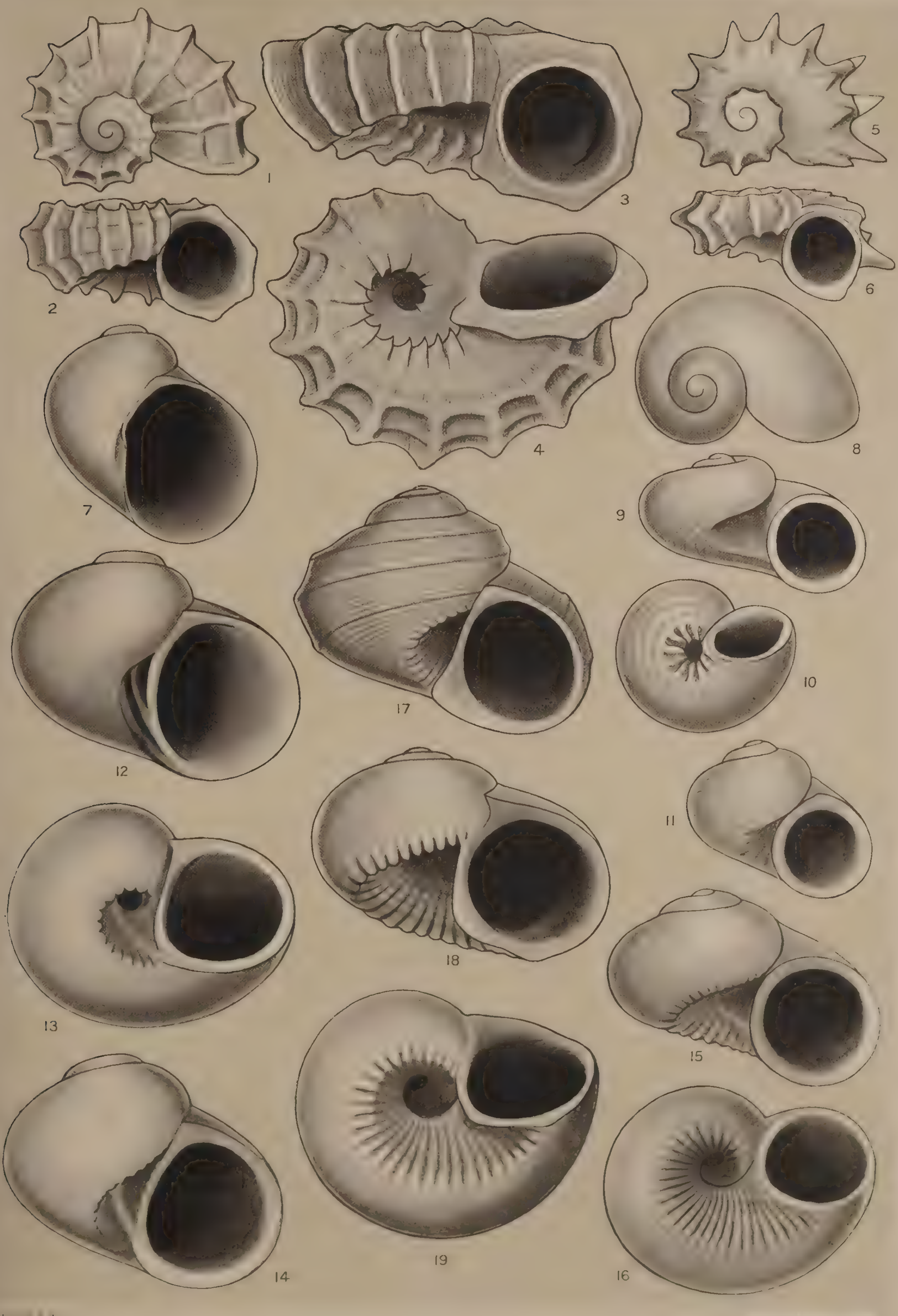
Fig. 12. *Cirsonella simplex*, n.sp. (Holotype). 1·4 × 1·75 mm.

Figs. 13, 14. *Cirsonella pisiformis*, n.sp. (Holotype). 1·3 × 1·45 mm.

Figs. 15, 16. *Cirsonella paradoxa*, n.sp. (Holotype). 1·05 × 1·45 mm.

Fig. 17. *Argalista variecostata*, n.sp. (Holotype). 1·8 × 2·3 mm.

Figs. 18, 19. *Argalista rotella*, n.sp. (Holotype). 1·1 × 1·6 mm.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

MOLLUSCA FROM NEW ZEALAND

# PLATE LI

Figs. 1, 2. *Zeminolia luteola*, n.sp. (Holotype). 4 × 5·5 mm.

Fig. 3. *Zeminolia vera*, n.sp. (Holotype). 3·5 × 5·4 mm.

Fig. 4. *Zeminolia benthicola*, n.sp. (Holotype). 5 × 5·5 mm.

Fig. 5. *Lissotesta caelata*, n.sp. (Holotype). 0·85 × 0·8 mm.

Fig. 6. *Lissotesta conoidea*, n.sp. (Holotype). 1·4 × 1·0 mm.

Fig. 7. *Lissotesta aupouria*, n.sp. (Holotype). 1·9 × 1·9 mm.

Fig. 8. *Liotella rotuloides*, n.sp. (Holotype). 0·7 × 1·4 mm.

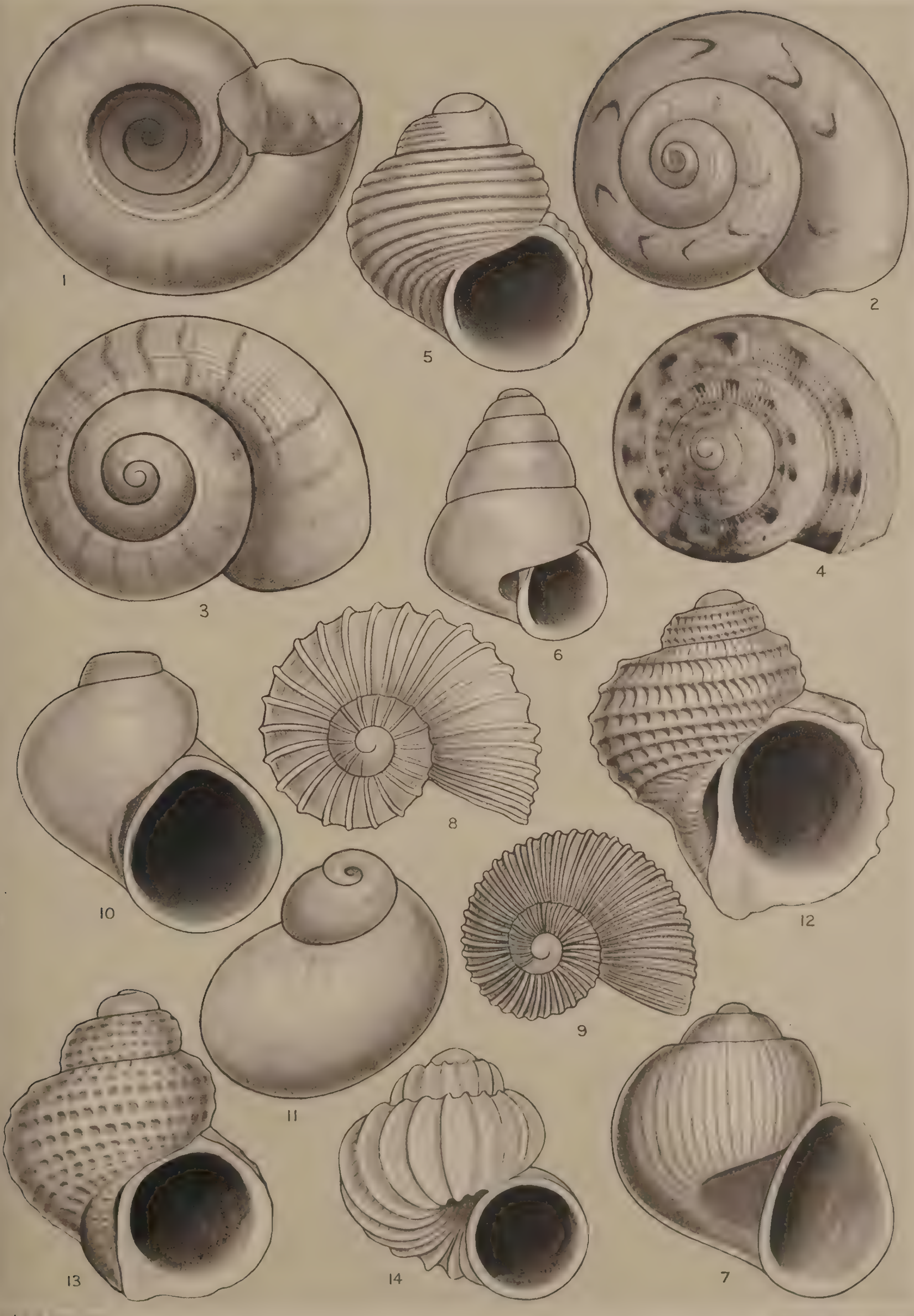
Fig. 9. *Liotella aupouria*, n.sp. (Holotype). 0·6 × 1·2 mm.

Figs. 10, 11. *Conjectura atypica*, n.sp. (Holotype). 1·8 × 1·7 mm.

Fig. 12. *Crosseola intertexta*, n.sp. (Holotype). 1·8 × 1·65 mm.

Fig. 13. *Crosseola favosa*, n.sp. (Holotype). 1·65 × 1·4 mm.

Fig. 14. *Brookula annectens*, n.sp. (Holotype). 1·1 × 1·2 mm.


1
5
2
3
6
4
8
12
10
9
11
13
14
7

MOLLUSCA FROM NEW ZEALAND

## PLATE LII

Fig. 1. *Haurakia finlayi*, n.sp. (Holotype). 2·9 × 1·6 mm.

Fig. 2. *Haurakia duplicata*, n.sp. (Holotype). 2·85 × 1·7 mm

Fig. 3. *Haurakia duplicata exuta*, n.subsp. (Holotype). 2·65 × 1·6 mm.

Fig. 4. *Haurakia aupouria*, n.sp. (Holotype). 2·05 × 1·25 mm.

Fig. 5. *Haurakiopsis pellucida*, n.gen. et sp. (Holotype). 1·6 × 1·1 mm.

Fig. 6. *Merelina cochleata*, n.sp. (Holotype). 1·6 × 0·87 mm.

Fig. 7. *Merelina crispulatus*, n.sp. (Holotype). 1·65 × 0·9 mm.

Fig. 8. *Merelina manawatawhia*, n.sp. (Holotype). 1·75 × 0·98 mm.

Fig. 9. *Merelina crassissima*, n.sp. (Holotype). 1·5 × 1 mm.

Fig. 10. *Merelina paupereques*, n.sp. (Holotype). 2·1 × 1·4 mm.

Fig. 11. *Promerelina tricarinata*, n.sp. (Holotype). 1·4 × 0·8 mm.

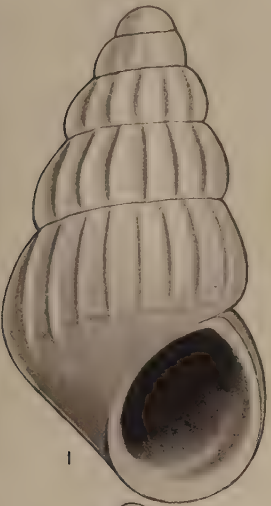
Fig. 12. *Austronoba iredalei*, n.sp. (Holotype). 2 × 1·2 mm.

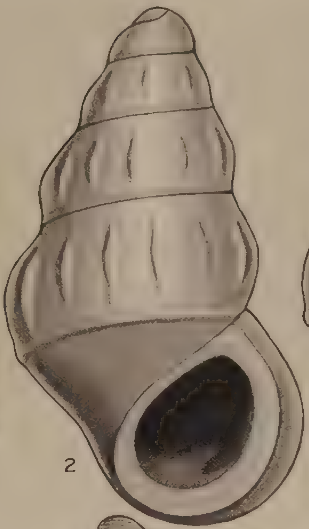
Fig. 13. *Coenaculum secundum*, n.sp. (Holotype). 1·5 × 0·5 mm.

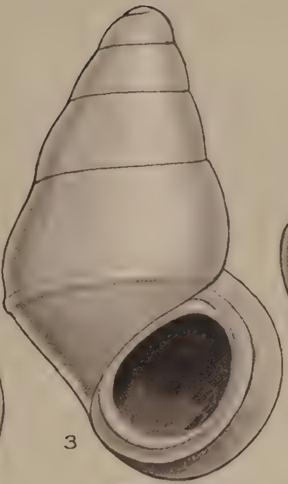
Fig. 14. *Manawatawhia analoga*, n.gen. et sp. (Holotype). 1·8 × 0·7 mm.

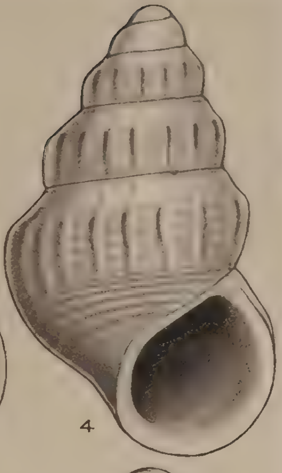
Fig. 15. *Nobolira cochlearella*, n.sp. (Holotype). 1·9 × 0·9 mm.

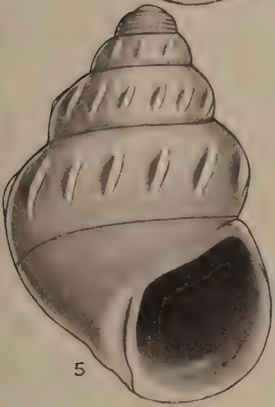
Fig. 16. *Nobolira manawatawhia*, n.sp. (Holotype). 2·1 × 1·25 mm.

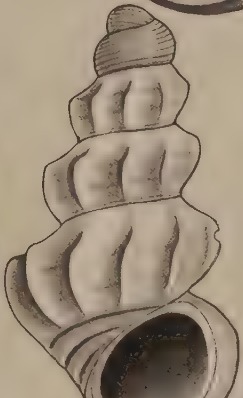

1

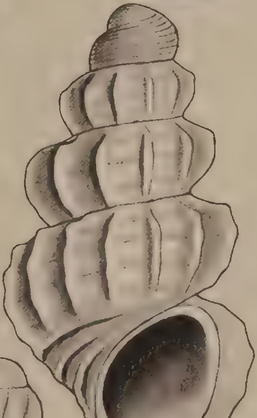

2

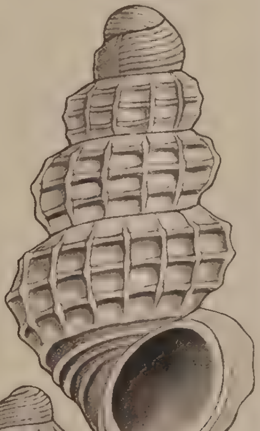

3

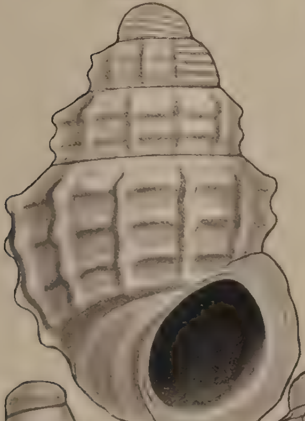

4

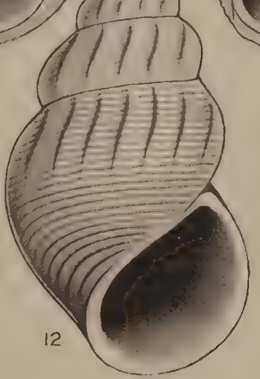

5

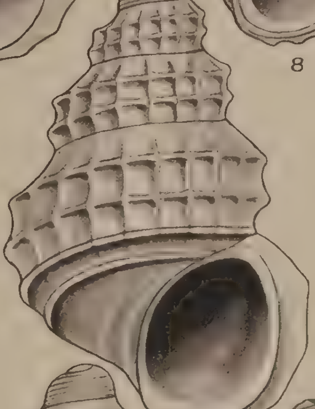

6

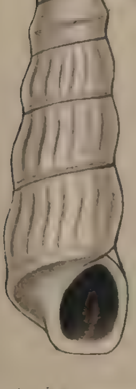

7

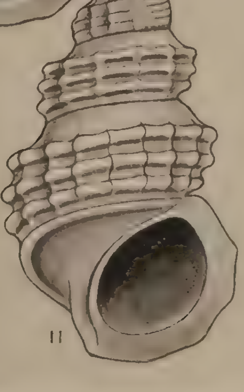

8

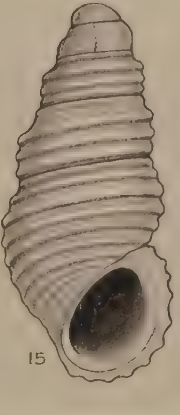

9

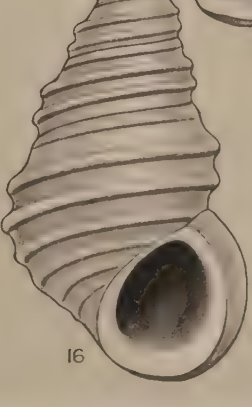

12

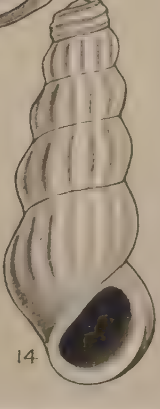

10


13


11


15


16


14

[illegible] del.

MOLLUSCA FROM NEW ZEALAND

# PLATE LIII

Fig. 1. *Estea porrectoides*, n.sp. (Holotype). 2·55 × 1·1 mm.

Fig. 2. *Estea subrufa*, n.sp. (Holotype). 2 × 1 mm.

Fig. 3. *Estea manawatawhia*, n.sp. (Holotype). 2·7 × 1·4 mm.

Fig. 4. *Estea crassicarinata*, n.sp. (Holotype). 1·5 × 0·8 mm.

Fig. 5. *Rissoina manawatawhia*, n.sp. (Holotype). 3·7 × 1·4 mm.

Fig. 6. *Rissoina aupouria*, n.sp. (Holotype). 8·5 × 3·5 mm.

Fig. 7. *Rissoina achatinoides*, n.sp. (Holotype). 4·8 × 1·8 mm.

Fig. 8. *Notosetia subtenuis*, n.sp. (Holotype). 1·2 × 0·8 mm.

Fig. 9. *Notosetia porcellanoides*, n.sp. (Holotype). 1·35 × 0·88 mm.

Fig. 10. *Notosetia subgradata*, n.sp. (Holotype). 1·5 × 1·1 mm.

Fig. 11. *Notosetia aoteana*, n.sp. (Holotype). 1·2 × 1 mm.

Fig. 12. *Notosetia aupouria*, n.sp. (Holotype). 1·9 × 1·25 mm.

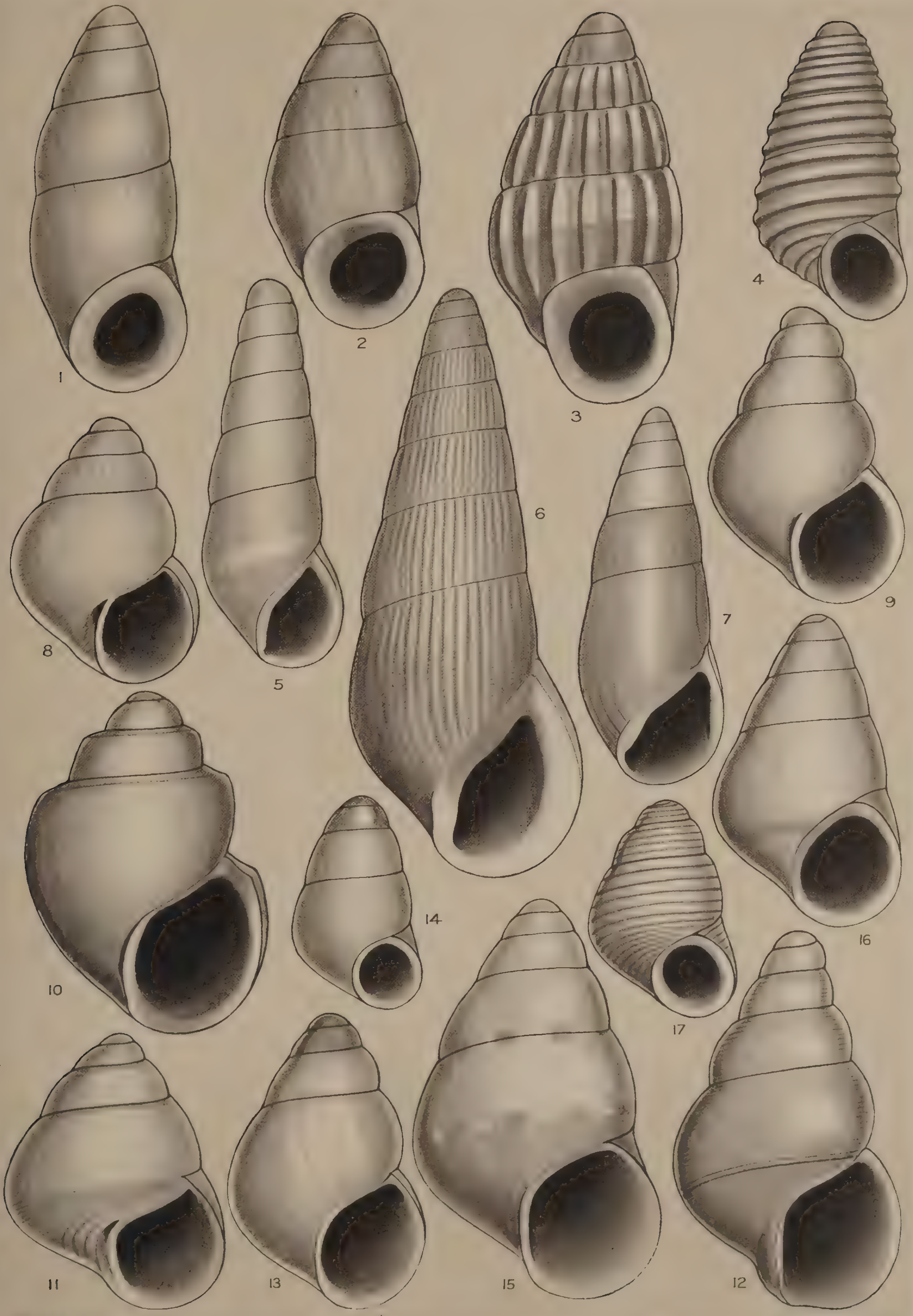
Fig. 13. *Dardanula roseospira*, n.sp. (Holotype). 1·4 × 0·95 mm.

Fig. 14. *Dardanula minutula*, n.sp. (Holotype). 0·95 × 0·55 mm.

Fig. 15. *Dardanula tenella*, n.sp. (Holotype). 2·1 × 1·3 mm.

Fig. 16. *Dardanula pallida*, n.sp. (Holotype). 1·65 × 1·05 mm.

Fig. 17. *Estea crassicordata*, n.sp. (Holotype). 0·9 × 0·6 mm.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

A. W. B. P. del.

MOLLUSCA FROM NEW ZEALAND

## PLATE LIV

Fig. 1. *Zaclys paradoxa*, n.sp. (Holotype). 2·1 × 0·9 mm.

Fig. 2. *Notosinister aupouria*, n.sp. (Holotype). 4·3 × 1·3 mm.

Fig. 3. *Zebittium laevicordatum*, n.sp. (Holotype). 4·05 × 1·5 mm.

Fig. 4. *Paramendax apicina*, n.gen. et sp. (Holotype). 5·4 × 1·45 mm.

Fig. 5. *Mendax attenuatispira*, n.sp. (Holotype). 5·4 × 1·3 mm.

Figs. 6, 7. *Zerotula crenulata*, n.sp. (Holotype). 0·4 × 1·1 mm.

Fig. 8. *Chemnitzia lawsi*, n.sp. (Holotype). 2·35 × 0·6 mm.

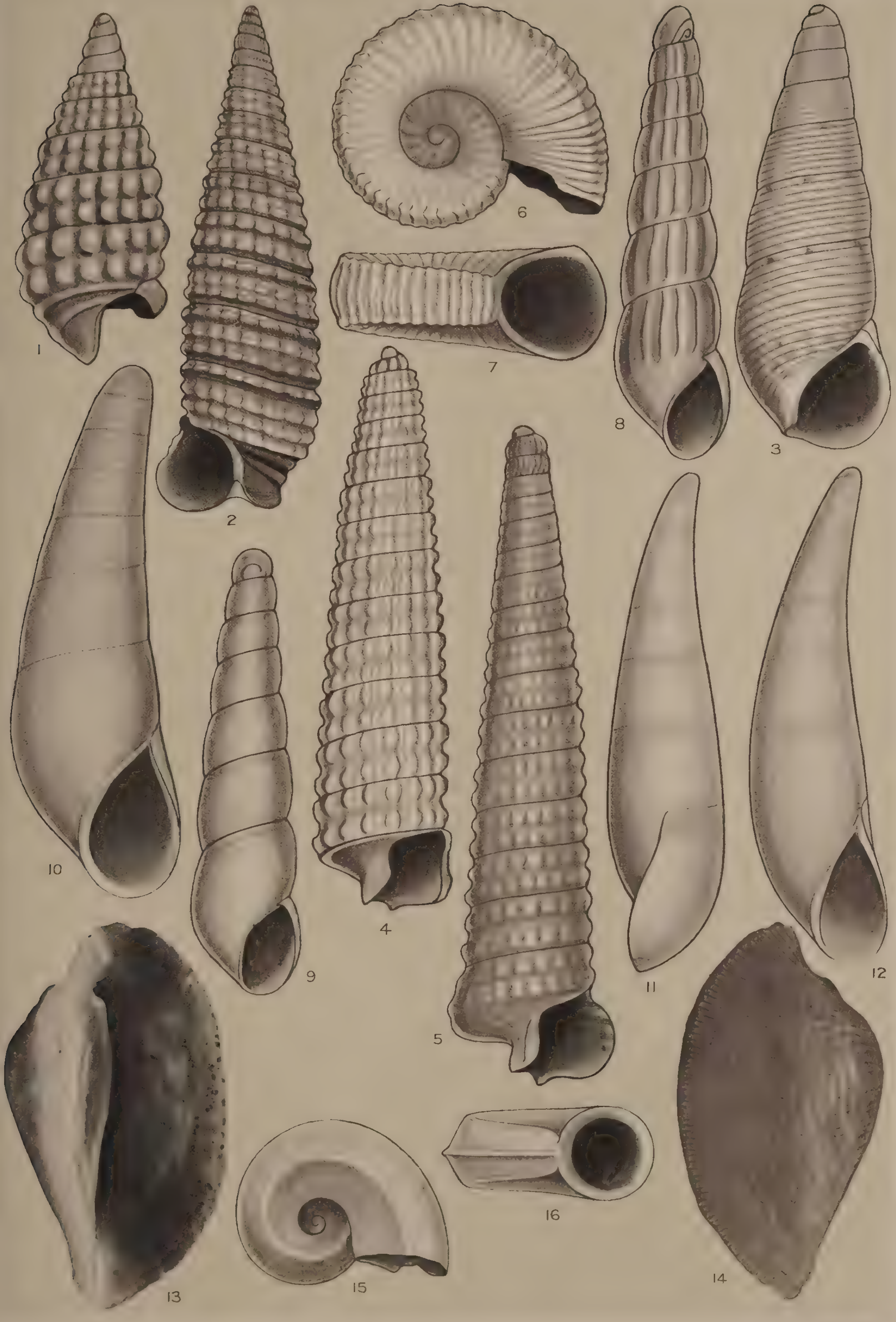
Fig. 9. *Eulimella aupouria*, n.sp. (Holotype). 2·25 × 0·58 mm.

Fig. 10. *Balcis aupouria*, n.sp. (Holotype). 3·75 × 1·2 mm.

Figs. 11, 12. *Balcis bollonsi*, n.sp. (Holotype). 2·8 × 0·7 mm.

Figs. 13, 14. *Pedicularia maoria*, n.sp. (Holotype). 4·9 × 2·5 mm.

Figs. 15, 16. *Zerotula triangulata*, n.sp. (Holotype). 0·55 × 1·1 mm.


6
1
7
8
3
2
10
4
9
11
12
5
13
16
15
14

A. W. B. P. del. et photo.

MOLLUSCA FROM NEW ZEALAND

## PLATE LV

Fig. 1. *Closia maoria*, n.sp. (Holotype). 7 × 5 mm.

Fig. 2. *Closia profunda* (Suter, 1909) (Holotype). 5·8 × 3·8 mm.

Fig. 3. *Marginella* (*Glabella*) *pygmaeiformis*, n.sp. (Holotype). 4·8 × 3 mm.

Fig. 4. *Marginella* (*Glabella*) *manawatawhia*, n.sp. (Holotype). 5·9 × 3·2 mm.

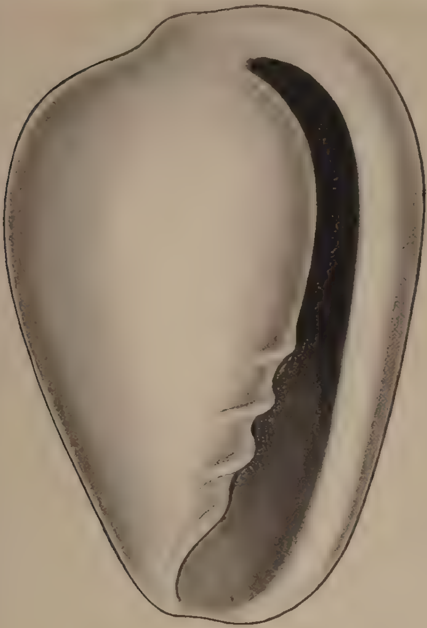
Fig. 5. *Marginella* (*Glabella*) *aupouria*, n.sp. (Holotype). 4·3 × 3·05 mm.

Fig. 6. *Marginella* (*Serrata*) *subamoena*, n.sp. (Holotype). 3·8 × 2·5 mm.

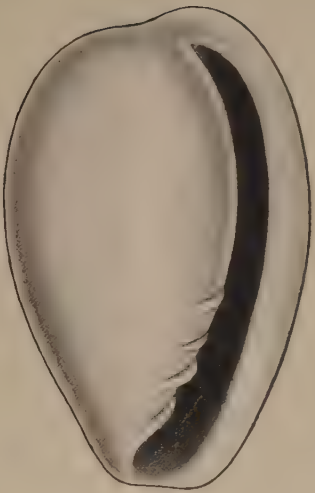
Fig. 7. *Retusa aupouria*, n.sp. (Holotype). 5·1 × 2·65 mm.

Fig. 8. *Egestas dissimilis*, n.sp. (Holotype). 2·8 × 1·45 mm.

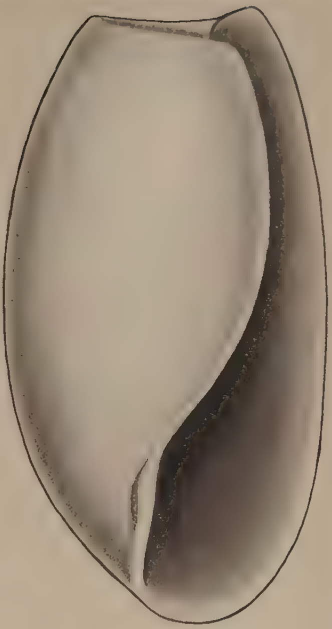
Figs. 9, 10. *Vermicularia maoriana*, n.sp. (Holotype). 2·4 × 1·1 mm.



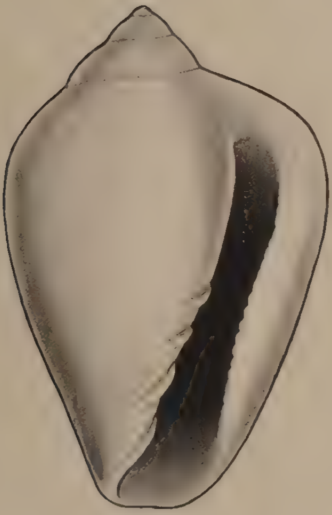
1



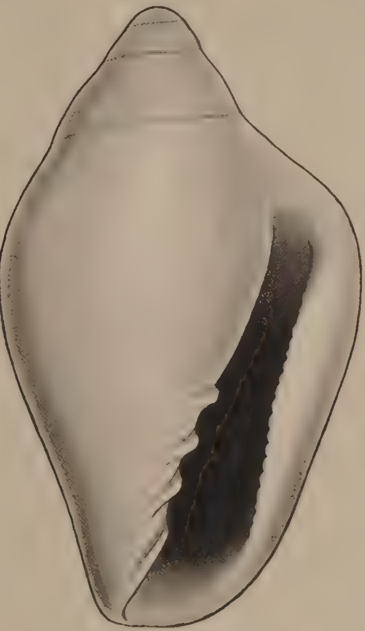
2



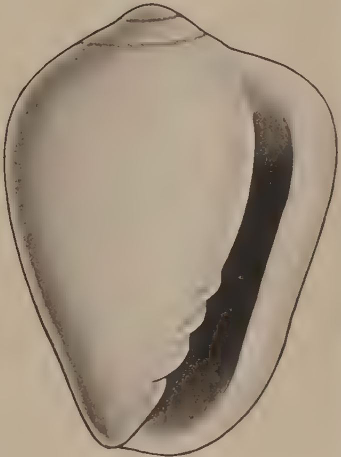
7



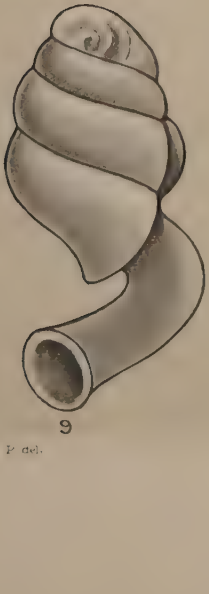
3



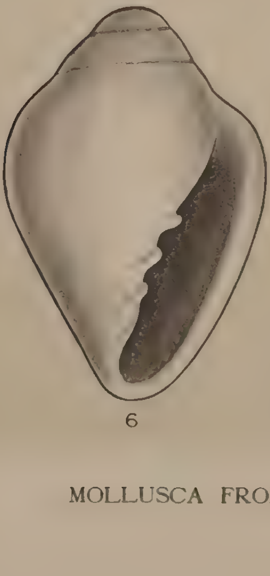
4



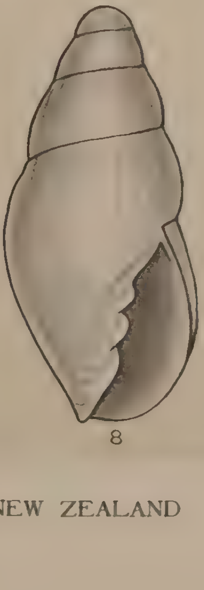
5



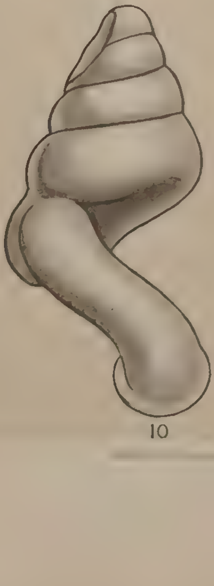
9



6



8



10

A W B P del.

MOLLUSCA FROM NEW ZEALAND

# PLATE LVI

Fig. 1. *Liratilia elegantula*, n.sp. (Holotype). 4·6 × 1·75 mm.

Fig. 2. *Liratilia sinuata*, n.sp. (Holotype). 6·2 × 2·6 mm.

Fig. 3. *Zemitrella sericea*, n.sp. (Holotype). 3·5 × 1·45 mm.

Fig. 4. *Zemitrella annectens*, n.sp. (Holotype). 3·1 × 1·2 mm.

Fig. 5. *Zemitrella turgida*, n.sp. (Holotype). 4·3 × 2·4 mm.

Fig. 6. *Zemitrella curvirostris*, n.sp. (Holotype). 3·9 × 1·9 mm.

Fig. 7. *Antimitrella laxa*, n.gen. et sp. (Holotype). 2·2 × 0·75 mm.

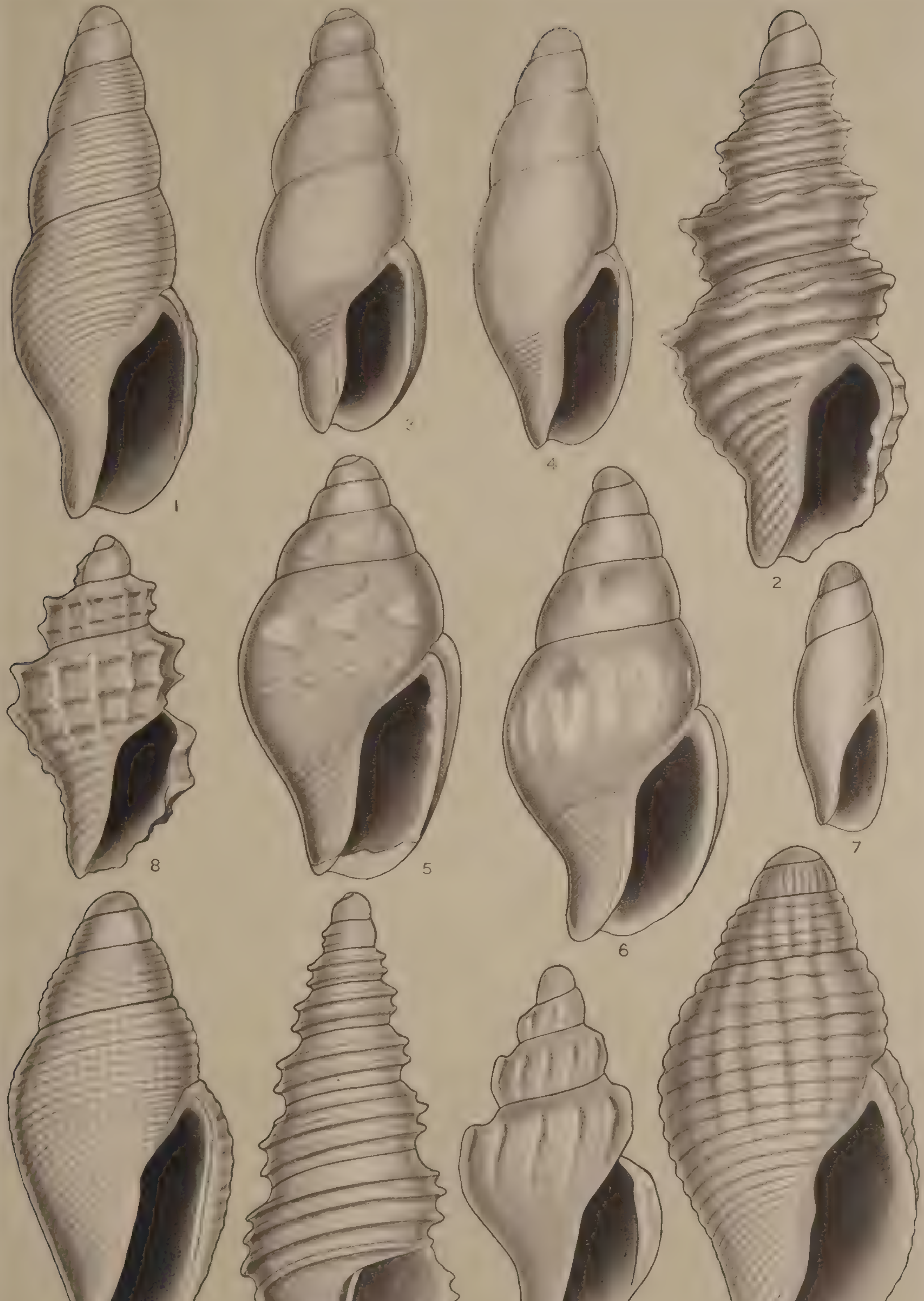
Fig. 8. *Nepotilla finlayi*, n.sp. (Holotype). 2·2 × 1·4 mm.

Fig. 9. *Mitrithara granulifera*, n.sp. (Holotype). 3·85 × 1·8 mm.

Fig. 10. *Mitrithara regis*, n.sp. (Holotype). 5·6 × 3·1 mm.

Fig. 11. *Stilla paucicostata*, n.sp. (Holotype). 1·7 × 0·95 mm.

Fig. 12. *Aclis maoria*, n.sp. (Holotype). 3·4 × 1·6 mm.


1
3
4
2
8
5
6
7
9
12
11
10

MOLLUSCA FROM NEW ZEALAND

[*Discovery Reports. Vol. XV, pp.* 223–284, *May*, 1937.]

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

# THE AGE OF FEMALE BLUE WHALES AND THE EFFECT OF WHALING ON THE STOCK

By

ALEC H. LAURIE, M.A.

# CONTENTS

INTRODUCTION . . . . . page 225
  Modern pelagic whaling . . . . . 225
  Scope of investigations . . . . . 226
BIOLOGICAL NOTES . . . . . 230
  External parasites . . . . . 230
  Length at sexual maturity . . . . . 230
  Incidence of pregnancy . . . . . 232
  Foetal sex ratio . . . . . 232
  Foetal growth curve . . . . . 233
  Ovaries: corpora lutea . . . . . 233
  Physical maturity . . . . . 236
  Summary . . . . . 238
THE RATE OF BREEDING . . . . . 239
  South Georgia data . . . . . 239
  Pelagic data . . . . . 241
AGE DETERMINATION . . . . . 243
  Doubtful corpora lutea . . . . . 244
  Length and corpora lutea . . . . . 244
  Recent ovulations . . . . . 246
  Corpora lutea frequencies for two seasons . . . . . 251
  Similarity of frequencies . . . . . 256
  Homogeneity of adult catch . . . . . 256
  Age and corpora lutea (Summary) . . . . . 259
THE AGE AT PHYSICAL MATURITY . . . . . 259
PRESENT SPAN OF LIFE . . . . . 260
POPULATION AND RECRUITMENT . . . . . 261
AVERAGE LENGTH OF BLUE FEMALES . . . . . 265
INCREASE OF IMMATURE WHALES IN THE CATCH . . . . . 266
SUMMARY . . . . . 267
LITERATURE CITED . . . . . 269
APPENDIX I: Blue whales taken in the Antarctic since 1904–5 and off the coast of Africa since 1910 . . . . . 270
APPENDIX II: Particulars of the collections of ovaries, 1934–6 . . . . . 271

# THE AGE OF FEMALE BLUE WHALES AND THE EFFECT OF WHALING ON THE STOCK

By Alec H. Laurie, M.A.

(Text-figs. 1–14)

## INTRODUCTION

INVESTIGATIONS into the life history of Southern Blue and Fin whales were begun in South Georgia as far back as 1913, when Barrett-Hamilton laid the foundations of the present methods of study. Members of the staff of the Discovery Investigations continued the work on a relatively large scale at Grytviken, South Georgia, from 1925 to 1931. Results of this work appear in *Discovery Reports* (1929, 1930, 1934, and 1935). The *Report* by Wheeler (1934) is important, because by the time it was published knowledge of Fin whales had advanced to the point at which tentative conclusions regarding the stock of whales and the effect of whaling thereon could be drawn.

Before proceeding to biological considerations it will be as well to outline the industrial background of pelagic whaling. The following résumé is intended to elucidate the conditions under which modern whaling is carried on and the material of this paper was gathered in order that the limitations of the data may be understood. For fuller information the reader is referred to works on whaling quoted in the bibliography.

I would record with gratitude the help and encouragement given me by Mr M. A. C. Hinton, F.R.S., with whom I have had many useful discussions. Dr A. S. Parkes, F.R.S., of the Medical Research Council, kindly assisted in the histological examination of ovaries. Thanks are also due to Mr T. Edser, of the Ministry of Agriculture and Fisheries, who has willingly spared the time to discuss population problems. I am grateful also to Dr Stanley Kemp, F.R.S., Dr N. A. Mackintosh, and Mr J. O. Borley for much useful criticism and advice. Contributions of material for this work are acknowledged in the appropriate place.

MODERN PELAGIC WHALING. The first whaling activities in the Falkland Dependencies were carried out from a land station. Here the boilers and other accessories for cooking the blubber, meat, and bones were located strategically around the flensing plan at the water's edge where the whales were hauled up and dismembered. A typical land station has been described by Mackintosh and Wheeler (1929, p. 262).

The earliest floating factories to be used in the Southern whaling grounds went to the South Shetlands in the first decade of this century. They were in essence floating oil refineries and cargo ships combined. Flensing and dismemberment of the carcasses were carried out alongside. These vessels had a production capacity of 300 barrels (50 tons) a day (Harmer, 1929), and their tonnage was 3000 to 4000. After the Great War factory ships increased in size and elaboration of equipment and used storage tanks for the oil instead of barrels. Ultimately nearly all the ships came to be equipped with slipways, cut usually in the stern but occasionally in the bows, through which the whales are hauled up on to the top deck. Factory ships are now self-contained, complete with storage tanks, and carrying provisions for several months. Most important development of all, as Hjort, Jahn, and Risting point out (1931, p. 15), thanks to the slipway which enables whales to be worked up on board, factories no longer rely on the shelter of light pack ice or a natural harbour to facilitate the work alongside but are able to work on the high seas unaffected by moderate changes in the weather. The fleet of catchers derives all its supplies from the parent ship, and the complete outfit is frequently at sea for six months without touching at a port. Tankers bring fuel oil and take away whale oil, so that the production of oil need be limited only by the numbers of whales that can be caught and worked up during a twenty-four hour day. Marshall (1930) gives an account of a season on board a factory ship. The whaling fleet employed in the Antarctic in recent years has consisted of from twenty to thirty ships, ranging from 6000 to 40,000 gross tonnage, with a production capacity of 1000 to 3600 barrels a day each (six barrels = one ton). These are owned by Norwegian and British companies. There is in addition one Japanese factory ship.

It can hardly be doubted that the recent enormous increase in numbers and capacity of the pelagic fleet must have an adverse effect on the stock of whales, and in many quarters it is felt that the danger of serious depletion is becoming acute. An investigation of the composition of the stock of whales in the Antarctic, and any means of measuring the effect of whaling thereon, should therefore be of value.

SCOPE OF INVESTIGATIONS. In considering the economic aspects of whaling, size of the stock, state of depletion, and so forth, a wider field than the South Georgia grounds claims our attention, and, since the stock of whales is being attacked in almost every part of the southern circumpolar seas, it becomes necessary to draw the material for a study of the biology of whales from as many sources as possible. Among other data are the reports of two investigators who sailed with factory ships and remained a season on board studying the whales in the same manner as was customary at Grytviken as they were hauled up and dismembered. Marshall visited the Ross Dependency in the factory ship 'C. A. Larsen' in 1928–9, and the writer spent the season 1932–3 on board the 'Southern Princess', thanks to the hospitality of the Southern Whaling and Sealing Company.

The larger and more important part of the pelagic catch has consisted up to date of Blue whales, and in this paper these alone will be dealt with. The urgent economic problems in whaling are then: what is the span of a Blue whale's life; is there any method of assessing the age of Blue whales caught in pelagic whaling; and what effect has whaling had on the stock of Blue whales in the Antarctic? An attempt is made in this report to answer these questions. That the conclusions are tentative is inevitable, since without intensive investigation over many years we are not justified in assuming the recurrent nature of the Antarctic population.

The legislation of most countries engaging in whaling now provides that no Blue whale under 60 ft. in length may be taken, no female running with a calf or calf accompanied by an adult may be shot, and the time of commencement and duration of the whaling season in Antarctic waters is determined. These regulations are mentioned because they affect the material, in so far as the data resulting from whaling are no longer an unrestricted sample of the stock.

The only observation that may have a bearing on the age of an adult male Blue whale is examination of the vertebral column to determine how far ankylosis has progressed, but that in itself is little use in determining the age of an individual after physical maturity is passed. The work of Mackintosh and Wheeler (1929) and Wheeler (1930) showed that the females offered more scope in examination, since the evidence of the breeding cycle could be used in estimating the age of the subject. According to Mackintosh and Wheeler (pp. 389–96) each ovulation gives rise, as in other mammals, to a corpus luteum, which either remains as a functional gland if the ovum is fertilized or rapidly regresses into a corpus albicans, which in Blue and Fin whales shows no sign of being ultimately absorbed. For simplicity in this paper the different classes of corpora will all be referred to as corpora lutea. The corpus luteum of pregnancy also regresses after parturition and becomes indistinguishable from the marks of other ovulations. Thus in these species of whales a permanent record of the number of ovulations is kept in the ovaries and can be used in a study of the life history of the female. The same principles with some modifications have been followed by the writer, and this paper is largely the result of a study of female Blue whales taken in pelagic whaling.

On board the 'Southern Princess' I had intended to carry out the same routine examinations as had been in vogue in South Georgia and which I used, *inter alia*, to investigate the possible similarity between South Georgia whales and those taken on the ice-edge. It soon became apparent, however, that the problem was too cumbrous unless drastic cuts were made in the number of observations on each whale so as to concentrate on those aspects of whaling which bore directly on questions of population and reproduction. The general biological interests of the subject had been well served by the investigators in South Georgia.

In 1932–3 I examined the carcasses of some 700 Blue whales of which approximately one-half were females. Examination of the females was confined to measurement of length, extraction of the ovaries, and estimation of the number of corpora lutea and albicantia thereon, measurement and notation of the sex of the foetus if present, and examination of the vertebral column for evidence of ankylosis. The results of these observations appear below in the section headed "Biological Notes". The condition of the mammary glands was also noted.

On the basis of the experience gained on this voyage, it was decided that the best results could be obtained by extending the study of the ovaries of adult Blue females to cover a wide field. Thus, instead of gaining some knowledge of the stock of whales in a single district, by collecting ovaries from the Blue females caught by pelagic whalers it would be possible to obtain information from all the areas which are commonly worked. In 1933–4 a small collection was made through the courtesy of the Southern Whaling and Sealing Company, in the season of 1934–5 eight British and Norwegian factory ships contributed collections of ovaries, and in 1935–6 ten factories co-operated. The collectors have in most cases kept records of the length and sexual condition of the whale from which the ovaries were taken, which information greatly enhanced the value of the collections.

For the success of this scheme thanks are due to the individual whaling companies and in particular to the secretary of the Norwegian Whaling Association, the late Sigurd Risting, and to his successor, Mr Harald B. Paulsen, without whose energetic co-operation only minor success could have been achieved.

The ovaries were taken from Blue females over 77 ft. in length while the carcasses were being dismembered on the decks of the factory ships. Each pair was tied securely with twine and a numbered metal tab was attached. (Cardboard labels were used in the small collection made in 1933–4 but these were torn from the ovaries during transit, rendering correlation of length with the condition of the ovaries impossible.) The length of each whale was recorded against the number allotted to the ovaries, together with the date of capture and the position of the ship on that date. The ovaries were stored in empty salt-meat casks filled with sea water, to which in 1934 was added half a litre of 40 per cent formalin. In 1935, after the corpora lutea of pregnancy had become important through the discovery of significant quantities of progestin therein (Callow, Laurie, and Parkes, 1935), a less destructive preservative was desired and salt was used. Eight pounds of commercial rock salt were added to the sea water in each barrel to make a saturated solution. This latter agent proved unsatisfactory both for the preservation of the ovaries as a whole and for the retention of the hormone, and many pairs of ovaries had to be thrown away. The barrels were shipped home as opportunity arose and arrived in London from three to six months after they had been filled.

Those ovaries which were not too decomposed were examined at the Natural History Museum, and, while distinctly offensive to smell and handle, they were with the exceptions mentioned good enough for the identification of corpora lutea, for which the only equipment required was a pair of rubber gloves and a carving knife. I must here gratefully record the forbearance and fortitude of the authorities and other workers in the Natural History Museum in allowing me to carry on this malodorous work on the premises. After examination, the corpora lutea of pregnancy were given to the Medical Research Council for research into the progestin content, and the rest of the ovaries were incinerated by the Sanitary Authority.

What follows is divided into three main parts: first, general biological notes chiefly from personal observations linking up pelagic Blue whales with what is known about South Georgia Blues, and breaking some new ground; second, consideration of the material and statistics supplied by the collectors of ovaries, and deductions as to the age of Blue females at maturity, the rate of ovulation, and the span of life; third, the application of these deductions to an estimate of the constitution of the stock of Blue females in the Antarctic, and of the effect of intensive whaling on the stock as a whole.

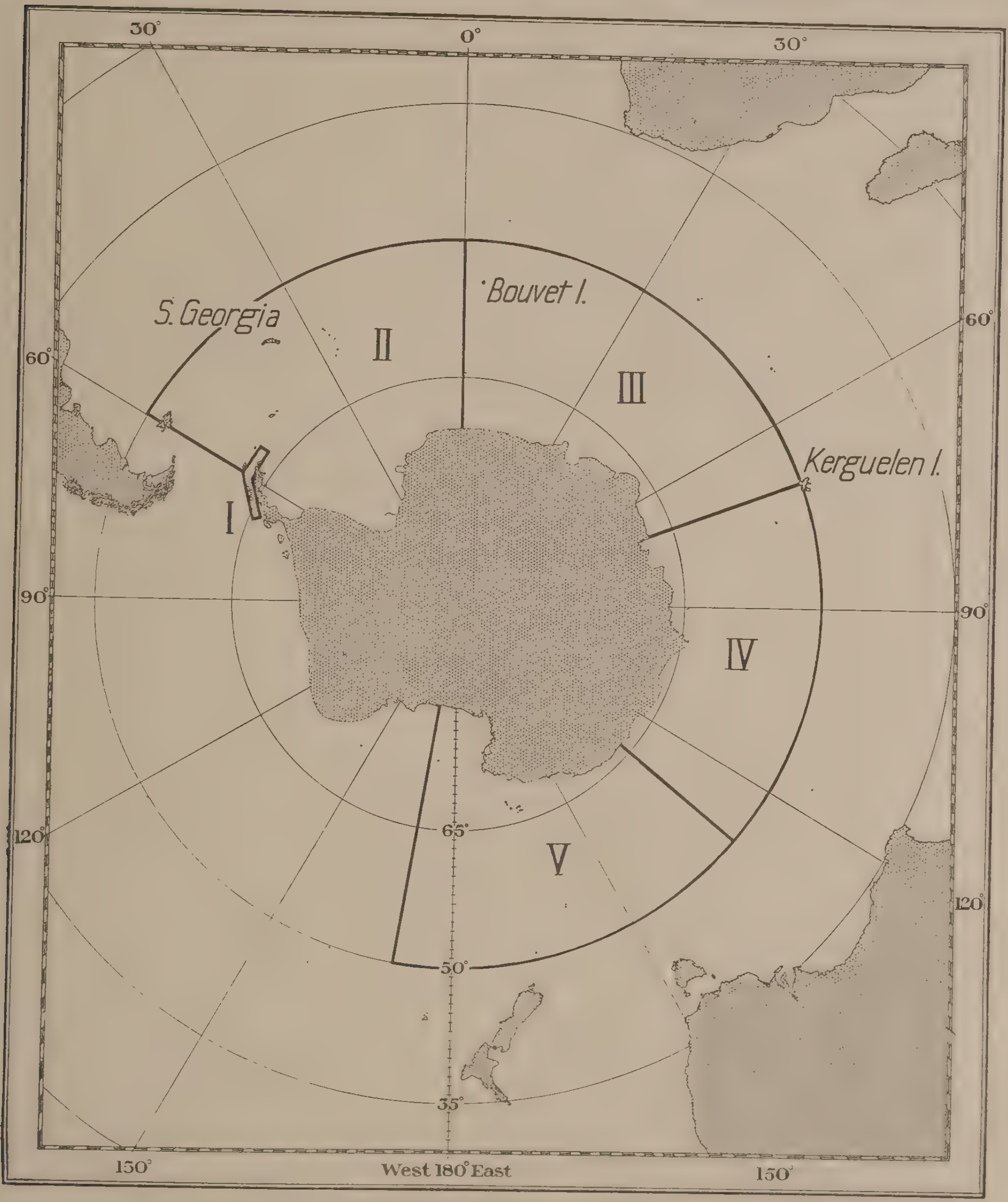

30°
0°
30°
S. Georgia
Bouvet I.
II
III
60°
60°
Kerguelen I.
I
90°
90°
IV
120°
65°
V
120°
50°
35°
150°
West 180° East
150°

Fig. 1. Antarctic whaling areas (after Hjort, Lie, and Ruud).

For clarity and uniformity the system of zoning the Antarctic whaling grounds used in the publications of the Norwegian Whaling Bureau has been adopted. A chart of the whaling grounds with identification marks is shown in Fig. 1. The small Area I is defined as being the waters fished by whalers working from the land stations or harbours in the Falkland Dependencies, Area II as the Weddell Area, Area III as Bouvet, Area IV as Kerguelen, and Area V as Ross Sea.

## BIOLOGICAL NOTES

Certain conclusions, which are discussed below, result from examinations undertaken on board the 'Southern Princess' in 1932–3 in the Kerguelen Area (IV).

EXTERNAL PARASITES. The skin of all Blue whales taken in the Antarctic is covered with whitish scars of various ages, usually oval, such as were found at South Georgia. All the other external parasites recorded in South Georgia are seen also in Antarctic Blue whales.

LENGTH AT SEXUAL MATURITY. In estimating the maturity or immaturity of Blue females, the presence or absence of pregnancy and the condition of the ovaries have been taken into account. From the results of one season's work it appears that there is little difference if any between the length at maturity of Blue females caught in pelagic whaling and those taken in South Georgia and Saldanha Bay.

Mackintosh and Wheeler showed that on the average sexual maturity in South Georgia Blue females coincides with a length of 77 ft. 9 in. (1929). (In the present report all measurements are given in feet. In previous reports the metric system has been used, since it was the natural medium for a study that was in many ways biometrical. It is felt that English feet will prove more acceptable for the present work, chiefly because all statistics of whales and foetuses supplied by the whaling industry are given in English feet, units largely used in Norway in marine matters.) Since whaling measurements on board factories are always taken to the nearest foot, it will be convenient for comparison to say that South Georgia Blue females become mature at an average length of 78 ft. In the material examined in Area IV in one season only there was one whale clearly mature at 77 ft. There were three whales clearly immature at 79 ft. and two at 80 ft. There were fourteen whales in a transition state with ripening follicles on the ovaries. Their length distribution was:

| Number of whales | Length (ft.) |
|---|---|
| 2 | 77 |
| 4 | 78 |
| 3 | 79 |
| 5 | 80 |

The length distribution of the three classes of whales is shown in Fig. 2. The obviously mature whales are those which either were pregnant or showed old corpora lutea in the ovaries. The average length of whales at the intermediate stage is 79 ft. and that of the earliest obviously mature, 80 ft. It is highly probable that the latter class had become mature in the previous winter, which, as Mackintosh and Wheeler have shown (p. 443), is probably the usual time for maturity to be reached, and that they had grown a foot or two since arriving at maturity. Six out of the eleven listed were pregnant, and since the foetuses were of the average size for the time of year (see Fig. 3) the mothers may be assumed to have conceived during the mean pairing season, which is in the middle of the southern winter (July).

The fact that the average size of the transition and mature classes is larger than would form an exact agreement with the South Georgia estimate of length at maturity does not mean necessarily that the length at maturity of these whales is greater. These whales were taken farther south than the South Georgia whales and in their southerly migration to the ice-edge have traversed a wider belt of ocean containing their food (*Euphausia superba*) and may be expected to have grown slightly more than those found at South Georgia. All things considered, there seems no reason to suppose that the Blue whales taken in the extreme south differ at all from those taken at South Georgia in point of growth and sexual maturity.

Some corroboration may be sought from the collection of ovaries which was made in 1935–6. It has been considered inadvisable to try to discriminate between definitely immature ovaries and ovaries in which ripening follicles appeared, because of the indifferent preservation of the material. The results are therefore shown in a different form. All the ovaries which had no corpora lutea, active or recessive, are classed as immature and, as before, those which showed corpora lutea are taken to have come from whales definitely mature. The arrangement of these classes by length is as follows:

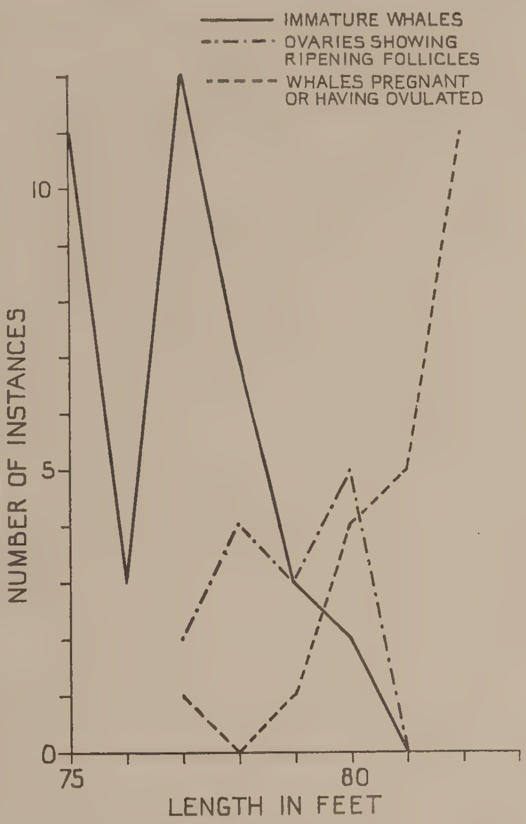


Fig. 2. Length distribution of immature and mature whales (1932–3).

| | Length (ft.) | | | | | |
|---|---|---|---|---|---|---|
| | 78 | 79 | 80 | 81 | 82 | 83 |
| No. of immature whales | 9 | 6 | 6 | 2 | 4 | 0 |
| No. of mature whales | 11 | 12 | 26 | 20 | 36 | 45 |

The data given above indicate the probability that some of the immature class should have been included in a transition stage, and since that has not been feasible the immature whales may appear to be unduly represented at the lengths of 80–81 ft. The general indication is, however, the same.

The possibility of clerical error in recording the data in connection with this 1935–6 sample must not be overlooked for reasons which are dealt with in the next section, where the entire collection is considered in detail. It is probably safe to conclude that this larger sample has nothing to show which conflicts with the results of personal examination of other material.

INCIDENCE OF PREGNANCY. It has been found that the most reliable guide to the percentage of adult whales pregnant is the presence or absence of a corpus luteum of pregnancy on the ovaries. Direct comparison has been made between the number of foetuses reported in the ship's whaling log and the number of pregnancies evidenced by the presence of corpora lutea of pregnancy on a sample of ovaries from the same ship. A higher percentage of pregnancy is indicated by the ovaries than by the log. There are two reasons for this discrepancy. Small foetuses tend to be missed, because on whaling ships operating under normal conditions time does not permit a careful search for foetuses. Only when a foetus is plainly to be seen on dismemberment of the mother will a record be made of it. Further, visibility on deck at night is poor, and, though floodlights suffice for general work, they are not strong enough to show up a foetus among the welter of meat, bones, and entrails which is inseparable from work on the congested deck of a factory ship. The discrepancy is of some importance, since it involves the calculation of fertility among adult Blue females. Further remarks will be made on this subject in the section on the rate of breeding.

I examined the ovaries of 180 whales on board the 'Southern Princess', and of these ninety-six showed the corpus luteum of pregnancy and were accompanied by a foetus. Four whales showed a functional corpus luteum, but no accompanying foetus was found nor did the condition of the uterus indicate that the whale was pregnant. These whales may be regarded as having quite recently ovulated; the corpus luteum was probably that of "pseudo-pregnancy". A small number of whales ovulating during the summer has been noted by Mackintosh and Wheeler among the whales examined at South Georgia (p. 390). In estimating the percentage of pregnancy among adults simply from a study of the ovaries it will be necessary to allow for those functional corpora lutea which may have been those of pseudo-pregnancy. There is no means of telling whether the number of ovulating whales recorded above represents a constant proportion of the total adult females. The most profitable way to treat the matter is probably to assume that the incidence of apparent pregnancy among whales from which the only evidence is that of the ovaries, as in material considered below, is slightly too high, and that the figure is a maximal one to be used with caution.

FOETAL SEX RATIO. 206 foetuses were measured by myself or the foreman in charge during the night. The sexes were represented as follows:

| | |
|---|---|
| Male ... ... | 112 or 54·4% |
| Female ... ... | 94 or 45·6% |

A slight preponderance of males over females is observed here and confirmed by records which were carefully kept by Mr R. Squire on board the 'Southern Empress'. The latter showed:

| | |
|---|---|
| Male ... ... | 102 or 53·6% |
| Female ... ... | 88 or 46·4% |

The tendency for males to predominate is further confirmed by the general statistics for the season 1933–4, shown on pp. 22–30 of *International Whaling Statistics*, vol. VI (1935). 1540 Blue whale foetuses are recorded of which 53·7 per cent were males and 46·3 per cent females.

FOETAL GROWTH CURVE. Fig. 3 shows the disposition of length in foetuses measured during the season 1932–3 on board the 'Southern Princess' and the 'Southern Empress'. The mean monthly lengths are shown. The freehand curve is a transcription of the mean growth curve shown by Mackintosh and Wheeler (p. 423). Monthly averages from the same source are shown also. The pelagic averages afford a striking confirmation of the South Georgia growth curve. As a result of the much greater number of observations, the monthly average lengths actually approach the mean curve more closely than do the South Georgia monthly averages (except for February, when only five measurements were taken on board the 'Southern Princess'). July may be fixed as the probable mean date of pairing of whales taken in pelagic whaling as of those taken in South Georgia. The similarity in breeding habit here shown is good evidence that the general way of living of South Georgia and pelagic Blue whales is much the same, that they pair at the same mean time of year, if not on the same grounds, and that the rate of foetal growth is identical.

OVARIES: CORPORA LUTEA. 180 pairs of ovaries were examined on board the 'Southern Princess' and a record was made of the numbers of corpora lutea and corpora albicantia. It was hoped that with the wealth of material at the investigator's disposal in pelagic whaling it might be possible to work out a scheme of age definition of Blue females from the distribution of numbers of corpora lutea, in the same way as was applied to Fin whales. Wheeler (1930) showed that with Fin whales a correlation could be made between the numbers of corpora lutea in the ovaries and the approximate age of the whale. The basis of the correlation was that certain numbers of corpora lutea were found to be more common than others. The intervals between these numbers indicate the mean number of ovulations, fertilized or unfertilized, between one breeding cycle and the next. Hence it was possible to calculate the approximate age of Fin females from the record of ovulations in the ovaries. Wheeler went further and correlated the attainment of physical maturity with the numbers of corpora lutea and hence with the age of the whale.

The present writer attempted to apply the same methods to Blue whales, but no regular occurrence of common numbers was observed. A frequency graph of corpora lutea numbers appears in Fig. 4 together with frequencies derived from examination of the large collections made in 1934–5 and 1935–6. These latter will be treated in more detail later. For the moment it will suffice to point out that in these three sets of frequencies peaks do not occur at regular intervals, nor do they occur at the same numbers of corpora lutea in the different years. Owing to this lack of agreement with

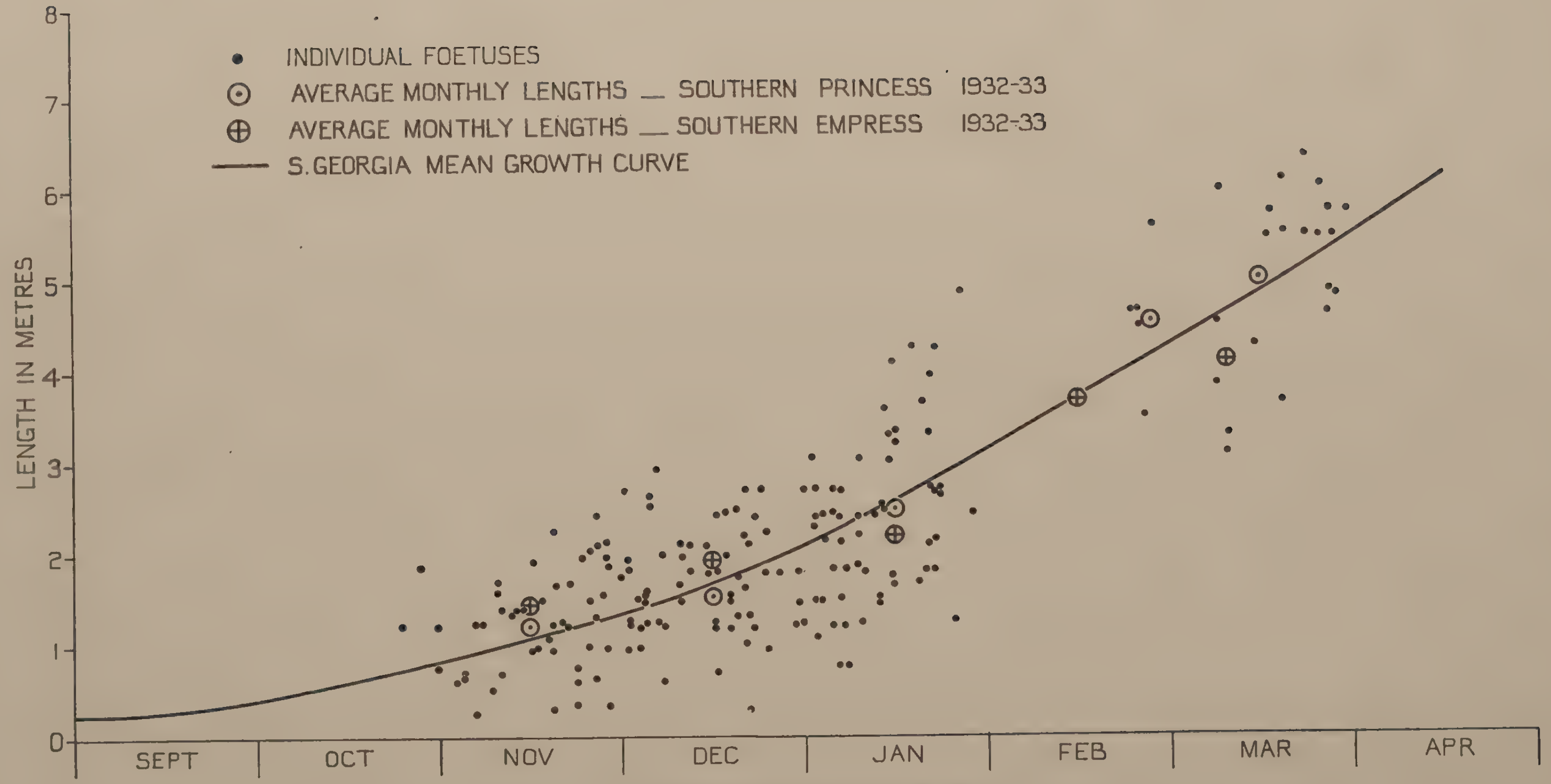


Fig. 3. Mean growth curve of foetuses.

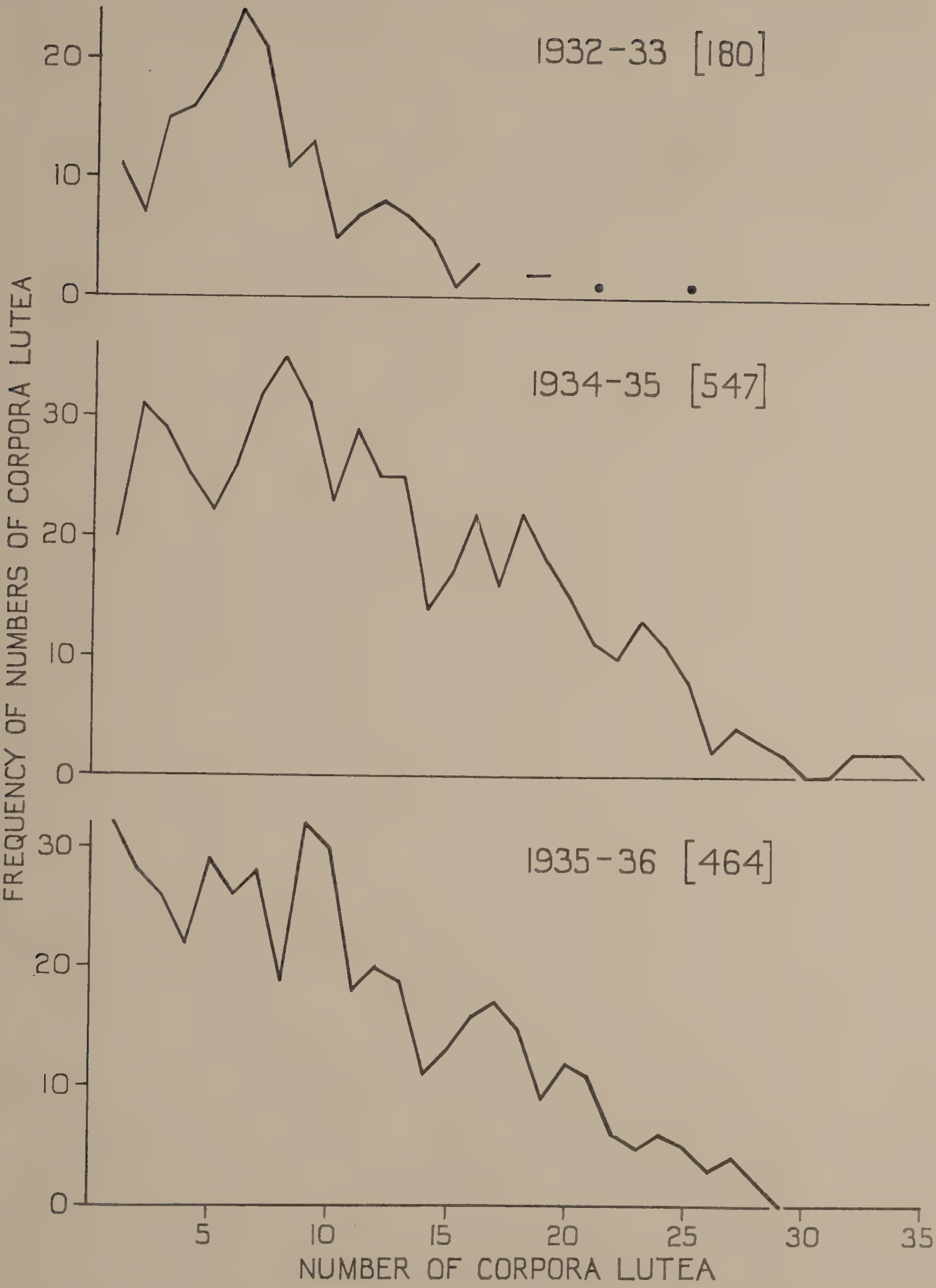


Fig. 4. Frequency of numbers of corpora lutea, Kerguelen Area, 1932–3, 1934–5, 1935–6.

Wheeler's findings with Fin whales, I have preferred to approach the problem by other methods, since it may be that conditions in Blue whales are such as to prevent the occurrence of peaks. (See p. 259.)

PHYSICAL MATURITY. The presence or absence of ankylosis of the vertebrae was examined in the same 180 whales whose ovaries had been examined. Wheeler (1930, pp. 408–9) showed that with the onset of physical maturity in many species of whales ankylosis of the centrum and epiphysis of the vertebrae takes place simultaneously but at different rates from both ends of the column and is completed in the anterior thoracic vertebrae. It was evident therefore that the criterion of complete maturity lay in ankylosis of the anterior thoracics, which I accordingly examined first. Frequently it was impossible in the heat of work on deck to examine other parts of the column after testing the thoracics, so that very often it was not feasible to make a diagnosis of partial ankylosis if complete fusion was absent. The crucial vertebrae, however, were always inspected. It is therefore possible to correlate the presence or absence of physical maturity and the numbers of corpora lutea in the ovaries with a view to correlating ultimately physical maturity with age.

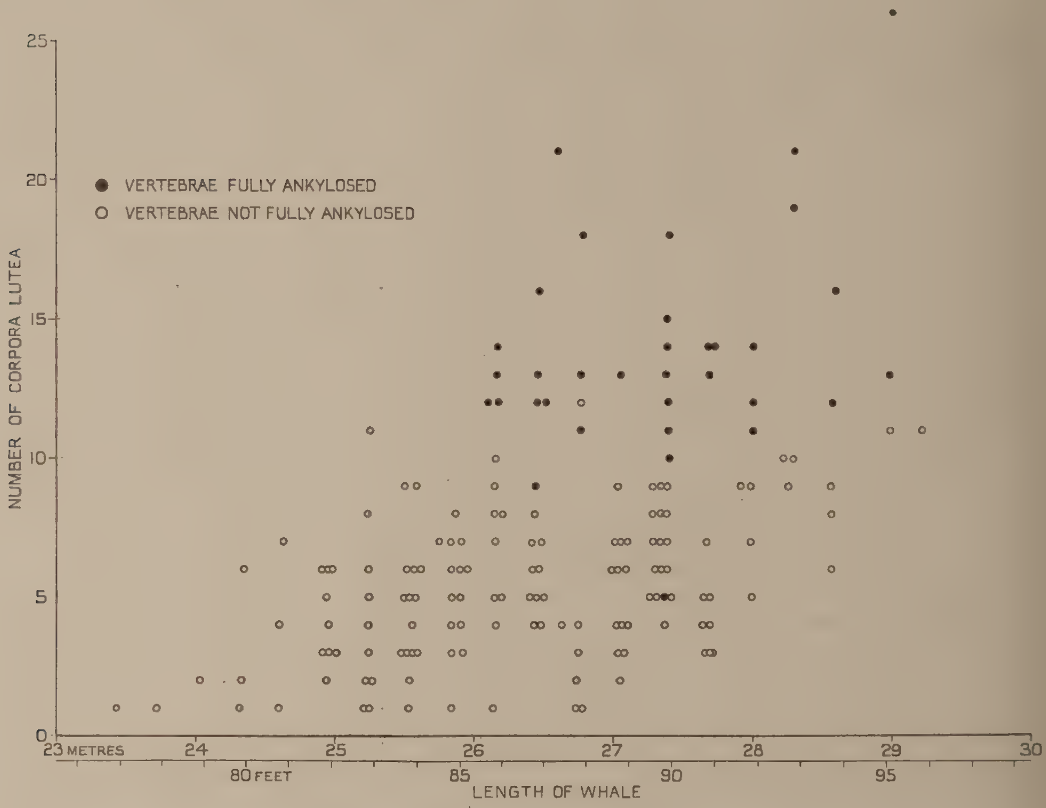


Fig. 5. Lengths of whales and number of corpora lutea.

In Fig. 5 are shown the numbers of corpora lutea in the ovaries of whales of stated lengths, and the distinction between physically immature and mature whales is made. The result is very striking and informative. It will be seen that nearly every whale having more than eleven corpora lutea is physically mature, while nearly every whale having less than eleven is physically immature. If we may assume that physical maturity is reached always at a definite age, we have here not only strong confirmation of the theory of the persistence and accumulation of the corpora lutea but also strong evidence that the number of corpora lutea is an absolute criterion of the age of a Blue whale. If the relation between age and number of corpora were a loose one, one would not expect to find such a sharp correlation between the numbers and such an important event in the whale's life as the attainment of physical maturity. With one exception physical maturity does not occur in female Blue whales under 86 ft. in length. At the same time there is shown to be a great diversity in the lengths to which whales may grow before complete ankylosis with the implied cessation of growth is attained. This is a good opportunity to emphasize for Blue whales the unreliability of length measurements as a guide to age (except in young whales) which Wheeler pointed out for Fin whales (p. 409). The probability is that maturity comes at the same approximate age in all female Blue whales, but at what great divergences of length has been seen in Fig. 6. Whether or not this divergence is due to the varying experience of each whale in numbers of young produced, the exertion of which might easily upset the growth rate, it is impossible to say. It is interesting to note that a Blue whale can attain to considerable length (90 ft.) and to physical maturity with but five corpora lutea to its credit, as one instance shows. Such a situation can perhaps only exist if the whale became pregnant at an early ovulation in each breeding season, thus reducing the number of ovulations to the minimum for its age. This may be an exceptional whale, but its interest lies in the probability that several pregnancies, each following the last as quickly as was practicable, have not interfered with growth, since the whale grew to a length well above the average before reaching physical maturity.

Another form of graphical treatment (Fig. 6) contrasts in a different way the lengths of, and the numbers of corpora lutea in, physically mature and immature whales. This graph shows the average number of corpora lutea exhibited by each length class of whale, lengths being taken at intervals of 1 ft. The averages show that up to 85 ft. there is a fairly steady increase in numbers of corpora lutea with increasing length, and, taking the means of adequate samples only, we can infer that length up to 85 ft. is a rough measure of age. But at the length at which collectively growth slows down, i.e. 85 ft., there is bound to be a sudden disproportionate increase in the numbers of corpora lutea. Subdivision of the data as shown in the figure indicates how many more corpora lutea are exhibited by the physically mature component of each length class over 85 ft. than by the physically immature component.

It is probably unsafe to try to make any further deductions from this material. To sum up, the position is that from the small amount of material at hand a correlation between the number of corpora lutea and the attainment of physical maturity has been established, the length at which the onset of physical maturity begins to limit the growth of some but not all Blue females is found, and from a deeper analysis it appears that up to the time of physical maturity there is some relation between length and the average number of corpora lutea. This relation will be further inspected when we deal with the larger collections of ovaries gathered in 1934–6.

It should be mentioned that the foregoing argument is confined solely to the material which I collected personally in 1932–3. Unfortunately the material collected subsequently, while satisfactory in other respects, contains no records of the degree of physical maturity of the whales from which the ovaries were taken.

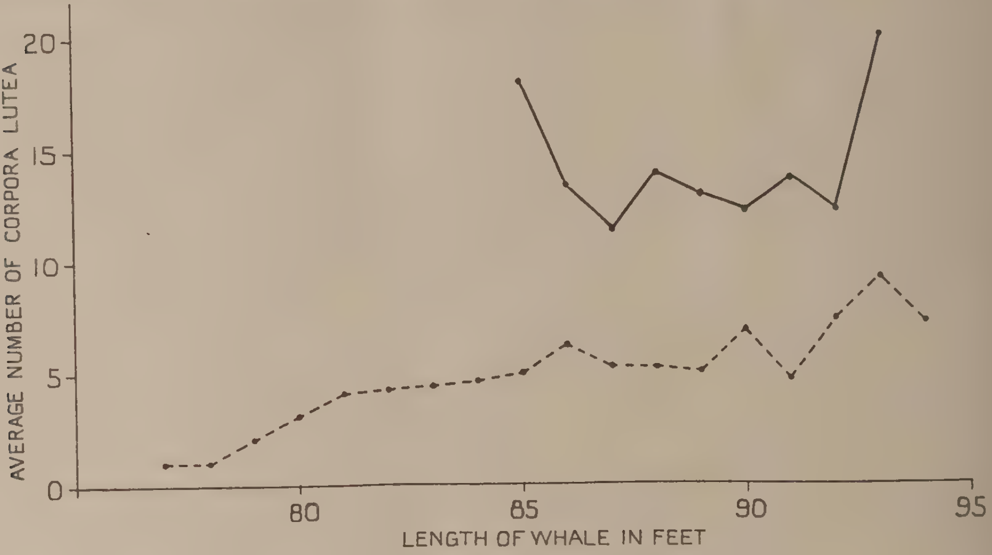


Fig. 6. Lengths of physically immature and mature whales (1932-3). (Pecked line, immature; solid line, mature.)

SUMMARY. 1. Blue females taken in pelagic whaling appear to attain sexual maturity on the average at the same length (78 ft.) as South Georgian whales.

2. The presence of a corpus luteum of pregnancy in the ovaries is taken to be the best index of pregnancy of the animal though some allowance must be made for whales ovulating in the summer and exhibiting a corpus luteum of ovulation, or pseudopregnancy.

3. A slight predominance of males is found in foetuses, in agreement with the foetal figures in *International Whaling Statistics*. Males are about 54 per cent of the total and females about 46 per cent.

4. The foetal growth curve as indicated by the mean monthly lengths of foetuses agrees closely with the mean growth curve for Blue whales taken in South Georgia. This is a strong indication that the Blue whales in both regions are essentially similar in their breeding habits and observe the same mean pairing season.

5. Frequencies of corpora lutea numbers in Blue whales do not show the maxima and minima on which a deduction of age was made for Fin whales.

6. Correlation of ankylosis of the vertebral epiphyses with corpora lutea numbers shows that physical maturity coincides with the accumulation of eleven to twelve corpora lutea in the ovaries. Blue females become physically mature at a wide range of lengths. Length is no guide to age except in a very rough way up to 85 ft. Growth in general may cease at 86 ft. (although females are occasionally found 99 ft. long).

## THE RATE OF BREEDING

A knowledge of the breeding cycle is essential to any calculations as to the condition of the stock and the effect of whaling thereon. Mackintosh and Wheeler have shown (p. 430) that the cycle of pairing, pregnancy, parturition, lactation, and recuperation among Blue whales cannot, except in very exceptional circumstances, take less than two years. Pregnancy is shown to take ten to eleven months, so that one year is virtually occupied with gestation. The period of lactation was indicated to be of the order of six to seven months (p. 436), followed by the period of recuperation. These conclusions were arrived at from a variety of evidence, which included the measurements of the largest unweaned and the smallest weaned whales. Considerable data have accumulated since these conclusions were formulated, and it will be as well to examine the evidence from South Georgia afresh and that from the Antarctic whaling grounds.

SOUTH GEORGIA DATA. The estimate of the mean date of weaning was derived largely from a study of the calves. The present intention in the light of more data is to inspect the evidences for the duration of the lactatory function in adult females. The period of lactation and that of nursing need not necessarily coincide, though it is improbable that a whale would continue to secrete milk for many days after the calf had ceased to take it.

We will now consider the relative occurrence of the three classes of female whales, pregnant, lactating, and resting. Among the resting whales must be included those which have recently ovulated without becoming pregnant (pp. 247–9). As they are not pregnant they may be included among the non-productive class of resting whales.

| Month | Number pregnant | Number lactating | Number resting |
|---|---|---|---|
| May | 1 | 2 | 1 |
| June | 1 | 0 | 2 |
| July | 1 | 1 | 2 |
| August | 4 | 0 | 6 |
| September | 2 | 4 | 1 |
| October | 5 | 5 | 3 |
| November | 38 | 8 | 13 |
| December | 13 | 3 | 10 |
| January | 20 | 5 | 2 |
| February | 20 | 10 | 18 |
| March | 8 | 14 | 11 |
| April | 2 | 0 | 0 |
| Total | 115 (50%) | 52 (20%) | 69 (30%) |

The figures for South Georgia have been added to since the publication of Mackintosh and Wheeler's report. The number of pregnant, lactating, and resting whales found during the whole of the investigations at South Georgia and Saldanha Bay from 1925 to 1931 are now available. From the mass of this material only those whales are shown in the preceding table whose condition was definitely ascertained. The months are arranged to begin from the mean birth time of Blue whales (May).

The sequel of events in the cycle postulated that whales lactate first and recuperate afterwards. In a two-year cycle, nearly the whole of the first year being taken up with gestation, the second year would be divided into a lactation and a recuperation period. While it is not desired to emphasize the numerical importance of the table, it is interesting to note that from October to March, when most of the observations were made, the lactating and resting whales are fairly evenly distributed in relation to each other. In order to make a direct comparison with the suggested seven months' nursing period which should be at its maximum from May to the end of November, the percentages of lactating and resting whales in the catch have been computed for the two periods. During May to November 22 per cent were lactating and 28 per cent resting; during October to March 22 per cent were lactating and 27 per cent resting.

The average date of capture of lactating whales in the above table is February 15, with the highest incidence in a single month in March. This would at first sight imply that lactation continues substantially longer than seven months, i.e. to the end of November, as was previously suggested. It is possible that the original estimate of the lactation period may be revised in the light of these figures, but there are several reasons why the figures may be misleading. Some mothers who gave birth at the normal time (May) may find the southern waters too cold for their calves early in the season, or they may travel more slowly than other adult females. In either case they would arrive at the whaling grounds towards, or even after, the end of lactation. On the other hand, those mothers whose calves were born late might find the water warm enough for their young soon after birth, and would arrive to swell the numbers of lactating whales taken late in the season.

What is less likely to be misleading is the fact that a significant proportion of the catch were resting in the six months following the mean time of birth. It is difficult to believe that so many whales had given birth so early in the season that they had finished lactating by November, in which month thirteen resting whales out of a total of fifty-nine were taken, or as early as October, when three resting whales out of thirteen were found. One possible explanation is that some Blue whales take practically one year in gestation, and an unknown period, possibly more than seven months, in lactation, and by reason of their low condition after lactation are not able to resume breeding in the second winter after the previous pregnancy so that they occur in the catch the following summer as resting whales. The breeding cycle would then sometimes take three years, but the validity of this theory is discussed below (p. 243).

It is interesting to note that Hart (1935, p. 278) has shown that there are whales which appear to have stayed in the cold region all the winter and not migrated with the majority to the tropics. It may well be that some of these are the resting whales, which were so exhausted by lactation that they could not afford the long fasting journey to the tropics, where there is no *Euphausia superba*, and, staying south, missed the breeding period.

PELAGIC DATA. The season in which I investigated whales on board the 'Southern Princess' was the last for which we have first-hand information of the catch of lactating whales. In that season, the capture of lactating whales by the Norwegian fleet was prohibited, but a number of lactating whales were taken by British companies, although most gunners disliked to kill nursing mothers. The season was from October 23 to March 29. Of the 180 mature females which I examined in special detail during that time, sixteen or 9 per cent were in active lactation. Sixty-four (35 per cent) were resting, four more had a fresh corpus luteum but no foetus, and ninety-six (54 per cent) were pregnant. The occurrence of the lactating and resting whales was as follows:

| Month | No. lactating | No. resting |
|---|---|---|
| October | 0 | 1 |
| November | 1 | 8 |
| December | 0 | 15 |
| January | 3 | 15 |
| February | 4 | 15 |
| March | 8 | 10 |
| Mean occurrence | February 18 | January 15 |

The same suggestion of a longer lactation period is in these figures, but this case is even more likely to be misleading, because the latitude in which these whales were caught is higher (60–66° S) and the mothers who brought their young far south would take even longer in their passage. The high incidence of resting whales in the first part of the season again suggests that they are a distinct class.

In the data for the last two seasons, 1934–5 and 1935–6, the composition of the catch is different, since no lactating whales may now be caught. Occasionally one may be taken in error, but the proportion is so small as to be negligible, even if these whales were always recorded in the log books of the factory ships. There are now only two main classes of adult whales in the catch, pregnant and resting.

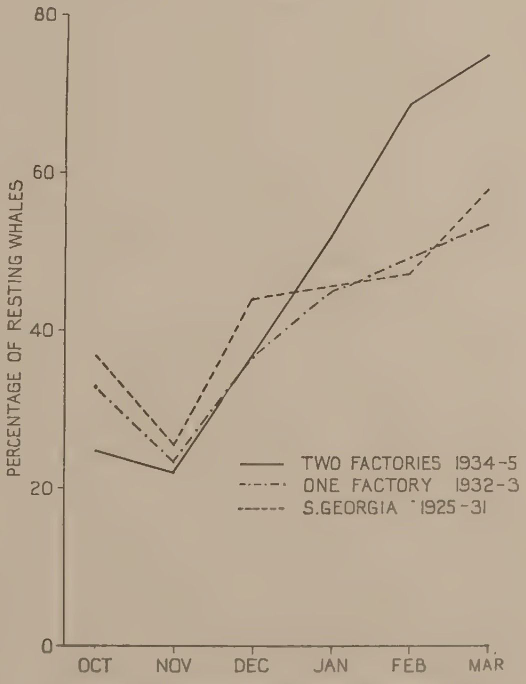


Fig. 7. Percentage of resting whales in the catch by months.

The monthly numbers of resting whales in the small material available from the work done in 1932–3 are shown graphically (Fig. 7) together with results from the 1934–5 material from two factory ships which started whaling in October (the rest started at the beginning of December). The 1934–5 material for these two ships is tabulated below to show the numbers and percentages of pregnant and resting whales in the monthly catch, as shown by the ovaries:

| Month | Ship | Pregnant |  | Resting |  |
|---|---|---|---|---|---|
|  |  | No. | Percentage | No. | Percentage |
| October | 'Southern Empress' | 13 | 76 | 4 | 24 |
|  | 'Southern Princess' | 2 | 67 | 1 | 33 |
| November | 'Southern Empress' | 15 | 75 | 5 | 25 |
|  | 'Southern Princess' | 16 | 80 | 4 | 20 |
| December | 'Southern Empress' | 11 | 58 | 8 | 42 |
|  | 'Southern Princess' | 11 | 69 | 5 | 31 |
| January | 'Southern Empress' | 8 | 57 | 6 | 43 |
|  | 'Southern Princess' | 6 | 40 | 9 | 60 |
| February | 'Southern Empress' | 11 | 35 | 21 | 65 |
|  | 'Southern Princess' | 4 | 25 | 12 | 75 |
| March | 'Southern Empress' | — | — | — | — |
|  | 'Southern Princess' | 3 | 25 | 9 | 75 |
| April | 'Southern Empress' | — | — | — | — |
|  | 'Southern Princess' | 2 | 100 | — | — |
|  | Totals | 102 | 55 | 84 | 45 |

It will be seen in Fig. 7 that the percentage of resting whales in the material above at the beginning of the season is 25, declining to 22 in November. There appears to be no significant change in the proportions of resting whales in the catch in October and November, but from November onwards to the end of the whaling season there is a steady increase. (The figures for April are too small to be included in the graph.)

On the same figure is shown the percentage of resting whales from the 1932–3 data, calculated solely in terms of pregnant and resting whales and excluding the lactating, so as to bring the material into line with the 1934–5 computations and all available South Georgia data treated in the same manner. The same general feature is observed.

A suggested explanation of the curve is as follows. The resting whales which are present at the beginning of the season and in November are probably whales which have stayed south all winter, such as Hart found. Their numbers are later supplemented by those whales which have finished lactating and join the resting class. As the season progresses more and more will have finished with lactation and become resting.

The ovary collections for two subsequent seasons gave results as shown in the table on p. 243. The number of non-pregnant whales is considerable in both years, but there is some disagreement between the percentages. For the sake of the argument that follows the two may be taken together to give an average of 58 per cent pregnant.

With a population of whales which is changing its composition from month to month, and which in any case may not be entirely representative of the whole stock, it is extremely difficult to arrive at certain conclusions on statistical grounds. But the scarcity of lactating whales in the early part of the summer, and the increasing proportion of resting whales as the summer wears on, suggest that lactating whales are to some extent absent and not sufficiently represented on the whaling grounds. If they are absent in a substantial proportion the pregnancy percentage would not be as high as 58, that is computing the pregnant whales as a percentage of the adult *stock*, in contrast to the adult *catch*. The pregnancy figure might in fact be low enough to warrant the conclusion that a considerable proportion of females are pregnant only once in three years.

| | Whales | Percentages |
|---|---|---|
| 1934–5 | | |
| Pregnant | 295 | 54 |
| Resting | 252 | 46 |
| 1935–6 | | |
| Pregnant | 284 | 61 |
| Resting | 180 | 39 |

If, however, we assume that a large proportion of females are absent, then we should find males correspondingly more numerous than females. This is not found to be the case, and it may therefore be argued that a large proportion of the adult females are not absent from the whaling grounds. But it may equally be argued that the lactating females are absent, and accompanied by an equal number of males. This hypothesis, while unlikely, is by no means impossible. There is little evidence either for or against family life among Blue whales.

The matter must at present be left in some doubt. It may be regarded as probable that while some females become pregnant every two years, an unknown proportion become pregnant only once in every three years.

## AGE DETERMINATION

We can now attempt to collate material from various sources in an endeavour to find a method of determining the age of female Blue whales by reference to the number of corpora lutea in the ovaries. It will be as well to recapitulate at this point what is known about the life history of the Blue whale from conception to sexual maturity. Mackintosh and Wheeler have shown that among Blue whales pairing takes place over an extended period in the southern winter, but that most pairing is in July (pp. 420–7). Evidence for this conclusion is a synthesis of indications from foetal growth statistics and data on the activity of the reproductive organs at different times of the year. From the foetal growth curve mentioned above and from records of the smallest calves taken and the largest foetuses found, it is concluded that birth takes place when the foetus reaches approximately 23 ft., on the average in April or May, after a gestation period of slightly over ten months (pp. 428–9). An important conclusion reached is that Blue females become mature sexually at about 78 ft., probably in June or July of the second year from birth.

DOUBTFUL CORPORA LUTEA. During the examination of the ovaries preserved in formalin (1934–5 collection) it was found that in ovaries which had large numbers of old corpora lutea from about twelve upwards there were occasional yellow bodies lying deep in the ovarian stroma and presenting the appearance of old corpora lutea. The shape of these bodies, however, was long and thin, unlike that of the genuine old corpora lutea, or more properly corpora albicantia, which are usually round or oval in cross-section, and there were fewer striations to be seen. The average length was 1 cm. and width 0·3 cm. It was at first thought that these bodies might represent old corpora lutea of ovulation or even of pregnancy. If this was so the conception of the permanency of corpora lutea would largely fall to the ground and their accumulation could be taken to represent increasing age only to a limited extent. If the corpora were to reach such small size they might well be on the point of being completely reabsorbed.

Dr A. S. Parkes kindly undertook to examine specimens of these corpora and compare them with undoubted relics of previous ovulations. Stained sections showed that the bodies were of definite luteal tissue, but with much less connective tissue in them. The crucial point seemed to be that these small corpora were deep in the ovary, and that no corresponding scar could be seen on the surface. A scar can always be seen with genuine corpora lutea. It was finally agreed that these bodies were not relics of genuine ovulations but had been caused by abortive follicles which had been on the way to maturing and then had regressed, forming luteal tissue, owing perhaps to the formation of a corpus luteum of pregnancy by another and better developed follicle. The luteal body arising from such a follicle is called a corpus atreticum.

It was therefore decided not to include these bodies in the counts of corpora lutea. Only those corpora which showed their scars of origin were considered in assessing the number of past ovulations.

The corpora atretica were not so easily found in the ovaries preserved in salt, partly because the flabbiness of the ovaries and their tough texture rendered slicing them difficult. Nor do I recall having seen more than two of these bodies in the fresh ovaries which I examined in 1932–3. These were not included in the count. In the event of future investigators using ovaries hardened in formalin, the distinction between corpora atretica and corpora albicantia must be carefully borne in mind, or the count of total corpora lutea may be inaccurate.

LENGTH AND CORPORA LUTEA. We now consider the ovaries of whales of 78 ft. and upwards.

The ovaries supplied by factory ships show some serious discrepancies. It was shown in Fig. 5 that I found that whales up to 81 ft. have in general few corpora lutea. Four whales showed one corpus, two showed two, there were none with three, one each with four and six, and one (an 81 ft. whale) with seven. The sample here, 180 whales, was twice as large as the average collection supplied by an individual factory and might be supposed, therefore, to be a fairer sample. Yet in the latter collections there are a number of ovaries purporting to come from whales 78–81 ft. long and showing a large range of corpora lutea numbers up to twenty-nine. I feel convinced that some error has occurred.

I found no whales of 79–81 ft. with more than seven corpora lutea in 1932–3, but if a greater number were properly associated with this length range the fact would emerge without fail in any reasonably large sample. Again, if a whale could ovulate any number of times up to twenty-nine before reaching a length of 81 ft. it might easily have accumulated 100 or more corpora lutea by the time it grew to, say, 86 ft., since old corpora are known to persist. As will be seen in the corpora lutea frequencies for two seasons, there is a definite cessation of numbers at thirty-four corpora in the first season and twenty-eight in the second. The chances of large numbers of corpora lutea occurring through multiple ovulations are too small to be of importance; twin or triple corpora lutea are found in less than 1 per cent of the total adult ovaries examined.

A table of the questionable ovaries is here given:

| Factory ship | Number of doubtful ovaries | Percentage of total collection | Factory ship | Number of doubtful ovaries | Percentage of total collection |
|---|---|---|---|---|---|
| 1934–5 | | | 1935–6 | | |
| 'Thorshammer' | 10 | 11 | 'Thorshammer' | 2 | 3 |
| 'New Sevilla' | 6 | 7 | 'New Sevilla' | 0 | 0 |
| 'Salvestria' | 4 | 4 | 'Southern Empress' | 7 | 8 |
| 'Southern Empress' | 3 | 3 | 'Southern Princess' | 0 | 0 |
| 'Southern Princess' | 1 | 1 | 'Sir J. C. Ross' | 9 | 10 |
| 'Sir J. C. Ross' | 0 | 0 | 'Hektoria' | 0 | 0 |
| 'Skytteren' | 3 | 7 | | | |

The fact that the percentage of small whales with large numbers of corpora lutea varies from ship to ship confirms the opinion that some mistake has been made. If these whales occur at all they would be found by all factory ships.

It has been decided, therefore, on all grounds to exclude from the calculations those ovaries which were stated to have come from whales up to 81 ft. long and which showed more than seven corpora lutea. The results of personal examination have been taken as the criterion.

The table overleaf based on the corrected figures shows the average number of corpora lutea found in whales of each unit of length from 78 to 83 ft. Two collections (547 and 464 whales respectively) are considered separately in order to show how far the results are consistent from one year to another.

The sharp increase in the average number of corpora lutea at 82 ft. suggests that whales of 78–81 ft. belong to one age group and that whales of 82 ft. and higher lengths belong to later year groups. There seems to be little doubt that the age distinction between 78–81 ft. whales and those of greater lengths is valid, since the difference is so marked. The distinction did not appear in the 1932–3 results, probably because the number of whales in each of these length groups was too small to be a good sample.

The range of corpora lutea numbers found in whales of 78–81 ft. is 0–7, but it is exceptional to find more than three; the average of all the numbers in this group is 1·91. The figures show that whales which were caught at 78 ft. and therefore probably became mature rather late in the preceding winter have succeeded in producing on the average one ovulation, and that the number of ovulations increases with length up to 85 ft. It seems likely that the number of ovulations averaged by 81 ft. whales, which probably had a flying start at the breeding season by reason of their forwardness in growth, represents the maximum number of ovulations normally possible in the first sexual season, i.e. 2·60.

| Length | Number of corpora lutea (average) | Number of whales | Length | Number of corpora lutea (average) | Number of whales |
|---|---|---|---|---|---|
| 1934–5 | | | 1935–6 | | |
| 78 | 1·0 | 16 | 78 | 1·05 | 20 |
| 79 | 2·17 | 19 | 79 | 2·05 | 18 |
| 80 | 1·45 | 32 | 80 | 2·15 | 32 |
| 81 | 2·33 | 22 | 81 | 2·90 | 22 |
| 82 | 7·90 | 30 | 82 | 6·70 | 40 |
| 83 | 10·00 | 31 | 83 | 8·10 | 45 |

Mackintosh and Wheeler have indicated that there is a fairly definite season of sexual activity (p. 429), and the foetal growth curve above (Fig. 3) corroborates this for pelagic Blue whales. It is impossible to say whether the onset of this activity is a natural internal occurrence coinciding with a certain degree of growth and subsequently regulated by the endocrine balance, as seems to be the case in other mammals, or whether conditions of light and temperature are the chief factors in starting the breeding cycle when the whales migrate towards the tropics.

Having disposed of the newly mature component in the adult female catch, it remains to find the average number of ovulations performed each year by the remaining adult females. The importance of discriminating between the catch and the total stock of whales, whose constituents may be never fully known, cannot be over-emphasized. But, since the bulk of the material comes from Antarctic waters, we must try to deduce as much as possible about the population in these waters, and, if feasible, extend our speculations to include such components as may be absent from the southern regions.

RECENT OVULATIONS. The corpus luteum of pregnancy is unmistakable; it is very large, with a mean diameter of 12·7 cm., and carries a very pronounced scar with a raised corona, which may be as much as 6 cm. in diameter (Mackintosh and Wheeler, p. 387). In addition to this, there are also found in ovaries old corpora lutea, varying in number, in different stages of regression into the state properly known as corpus albicans. Some of these latter are also large, but are unmistakable because of their dry fibrous structure and the presence of luteal matter, which tinges the regressed corpus yellow. Besides these recognized forms, I noticed, unfortunately only towards the end of the ovary examination, the occurrence of large regressing corpora, whose substance was soft and fairly well vasculated, and whose pinkish appearance seemed to indicate that they were corpora lutea of ovulation which had existed for a relatively short time. The diameter of these bodies ranged between 6 and 10 cm. (that is the mean diameter, for the bodies were seldom spherical but usually of ellipsoid shape). There is a fairly large difference between the diameter of the smallest of these bodies and the largest of the palpably older ones.

After this special kind of corpus luteum had been noticed, a few newly mature whales appeared with corpora which must have been of recent production. They are listed below.

| Serial number | Length of whale (ft.) | Number of recent corpora lutea | Number of old corpora lutea |
|---|---|---|---|
| 556 | 79 | 1 | 0 |
| 1462 | 81 | 2 | 0 |
| 1464 | 81 | 1 | 0 |
| 1612 | 81 | 3 | 0 |
| 1660 | 81 | 1 | 1 |

These corpora were identical in appearance with those which I had classed as new in the ovaries of older whales.

Lists of the ovaries in which these bodies were found are here given according to factories for the season 1935–6. The list could have been much greater if the importance of the bodies had been realized sooner, but the idea of measuring the corpora arose late in the examination of the ovaries, so that all the material is not included in these lists. Barrels were dealt with in the order of their arrival, and it thus happens that part of the

*Fl.F. 'Hektoria'*

| Serial number | Length of whale | Total corpora lutea | Corpora lutea of pregnancy | Number of recent corpora lutea | Diameter of recent corpora lutea (cm.) | Diameter of largest old corpus luteum (cm.) |
|---|---|---|---|---|---|---|
| 1453 | 87 | 5 | 1 | 3 | 6, 6 | 4 |
| 1474 | 85 | 13 | 1 | 2 | 6 | 3 |
| 1476 | 82 | 2 | 1 | 2 | 7 | — |
| 1479 | 89 | 12 | 1 | 3 | 6, 5 | 3 |
| 1481 | 95 | 22 | 1 | 2 | 6 | 4 |
| 1489 | 86 | 2 | 0 | 2 | 5, 6 | — |
| 1494 | 85 | 2 | 1 | 2 | 6 | — |
| 1496 | 86 | 7 | 0 | 1 | 7 | 3 |

| | |
|---|---|
| Number of whales considered in table | 8 |
| ,, in sample whose only recent corpus is of pregnancy | 12 |
| ,, in sample non-pregnant with no recent corpora | 15 |
| ,, in sample | 35 |

### *Fl.F. 'New Sevilla'*

| Serial number | Length of whale | Total corpora lutea | Corpora lutea of pregnancy | Number of recent corpora lutea | Diameter of recent corpora lutea (cm.) | Diameter of largest old corpus luteum (cm.) |
|---|---|---|---|---|---|---|
| 422 | 86 | 7 | 1 | 2 | 8 | 4 |
| 423 | 87 | 14 | 0 | 2 | 9, 7 | 5 |
| 424 | 84 | 5 | 1 | 2 | 6 | 4 |
| 427 | 83 | 8 | 1 | 3 | 7, 7 | 3 |
| 428 | 83 | 6 | 1 | 3 | 7, 7 | 3 |
| 429 | 88 | 18 | 1 | 3 | 9, 8 | 5 |
| 436 | 83 | 4 | 0 | 2 | 7, 5 | 3 |
| 440 | 87 | 20 | 1 | 3 | 7, 7 | 4 |
| 448 | 91 | 11 | 1 | 3 | 9, 7 | 5 |
| 450 | 91 | 23 | 1 | 3 | 8, 7 | 4 |
| 708 | 92 | 5 | 1 | 2 | 7 | 4 |
| 709 | 87 | 9 | 1 | 3 | 10, 7 | 5 |
| 710 | 88 | 5 | 1 | 5 | 8, 8, 7, 6 | — |
| 712 | 83 | 3 | 0 | 2 | 8, 7 | 3 |
| 716 | 89 | 9 | 1 | 3 | 9, 8 | 5 |
| 720 | 83 | 11 | 1 | 2 | 8 | 4 |
| 721 | 84 | 7 | 0 | 3 | 9, 8, 7 | 4 |

Number of whales considered in table ... ... ... ... ... ... ... 17
,, in sample whose only recent corpus is of pregnancy ... ... ... 2
,, in sample non-pregnant with no recent corpora ... ... ... 0
,, in sample ... ... ... ... ... ... ... ... ... 19

### *Fl.F. 'Thorshammer'*

| Serial number | Length of whale | Total corpora lutea | Corpora lutea of pregnancy | Number of recent corpora lutea | Diameter of recent corpora lutea (cm.) | Diameter of largest old corpus luteum (cm.) |
|---|---|---|---|---|---|---|
| 503 | 86 | 21 | 1 | 2 | 7 | 4 |
| 504 | 87 | 9 | 1 | 3 | 8, 7 | 3 |
| 525 | 91 | 3 | 1 | 3 | 7, 7 | — |
| 528 | 89 | 9 | 1 | 4 | 8, 9, 7 | 4 |
| 529 | 84 | 8 | 1 | 2 | 8 | 4 |
| 532 | 94 | 3 | 0 | 3 | 7, 6, 6 | 1 |
| 537 | 87 | 9 | 0 | 1 | 7 | 3 |
| 538 | 83 | 3 | 0 | 1 | 7 | 3 |
| 542 | 83 | 2 | 0 | 2 | 8, 7 | — |
| 563 | 85 | 19 | 0 | 1 | 7 | 4 |
| 565 | 84 | 9 | 0 | 2 | 8, 7 | 4 |
| 567 | 82 | 1 | 0 | 1 | 8 | — |
| 568 | 84 | 9 | 1 | 2 | 7 | 4 |
| 573 | 89 | 10 | 0 | 1 | 7 | 3 |
| 582 | 88 | 16 | 0 | 4 | 9, 6, 7 | 3 |

Number of whales considered in table ... ... ... ... ... ... ... 15
,, in sample whose only recent corpus is of pregnancy ... ... ... 40
,, in sample non-pregnant with no recent corpora ... ... ... 13
,, in sample ... ... ... ... ... ... ... ... ... 68

*Fl.F. 'Tafelberg'*

| Serial number | Length of whale | Total corpora lutea | Corpora lutea of pregnancy | Number of recent corpora lutea | Diameter of recent corpora lutea (cm.) | Diameter of largest old corpus luteum (cm.) |
|---|---|---|---|---|---|---|
| 1607 | 82 | 2 | 0 | 1 | 6 | 3 |
| 1611 | 83 | 13 | 1 | 2 | 8 | 4 |
| 1609 | 79 | 3 | 0 | 3 | 7, 5, 4 | — |
| 1613 | 84 | 21 | 1 | 3 | 8, 4 | 3 |
| 1619 | 89 | 20 | 1 | 3 | 6, 5 | 2·5 |
| 1668 | 88 | 23 | 2 | 4 | 9, 8 | 5 |
| 1670 | 89 | 9 | 0 | 2 | 8, 6 | 3 |
| 1676 | 83 | 1 | 0 | 1 | 8 | — |

| | |
|---|---|
| Number of whales considered in table ... ... ... ... ... ... ... | 8 |
| ,, in sample whose only recent corpus is of pregnancy ... ... ... | 34 |
| ,, in sample non-pregnant with no recent corpora ... ... ... | 20 |
| ,, in sample ... ... ... ... ... ... ... ... ... | 62 |

collections from several factories were treated in this way and are included in the list. When results are given as percentages or averages, they are based on the ovaries in the list and not on all ovaries from the ship in question.

In the list are shown, for whales over 81 ft. long, the length of the whale, total number of corpora lutea, the presence or absence of a corpus of pregnancy, the number of new corpora, their mean diameter, and the diameter of the largest old corpus in each case. It will be seen that there is mostly a difference of at least 2 cm. between the smallest recent corpus albicans and the largest obviously old one. The difference in volume is, of course, much greater, since the volume is a cubical function of the diameter.

There are three classes of whales in each of these collections, except that from the 'New Sevilla': pregnant, recently ovulated but not pregnant, and resting whales which do not appear to have ovulated at all during the previous winter. The range of recent ovulations in this material is three to five, but the majority showed one, two, or three. The average number of recent ovulations shown by whales with corpora lutea of pregnancy is as follows:

| Factory | Number of whales | Average recent ovulations |
|---|---|---|
| 'Hektoria' | 15 | 1·54 |
| 'New Sevilla' | 16 | 2·57 |
| 'Thorshammer' | 47 | 1·26 |
| 'Tafelberg' | 38 | 1·21 |
| Aggregate | 116 | 1·47 |

The number of ovulations performed by whales which appeared to have ovulated but did not become pregnant is:

| Factory | Number of whales | Average recent ovulations |
|---|---|---|
| 'Hektoria' | 3 | 1·33 |
| 'New Sevilla' | 9 | 2·25 |
| 'Thorshammer' | 8 | 1·50 |
| 'Tafelberg' | 4 | 1·75 |
| Aggregate | 24 | 1·80 |

The recently ovulated but non-pregnant whales show a slightly higher average than the pregnant whales, as might be expected since the occurrence of pregnancy would terminate ovulation. The relationship between the three classes and their effects on the average number of ovulations performed by the whole group is shown in the following table:

| Factory | Percentage pregnant | Percentage resting | Percentage recently ovulated but non-pregnant | Average number of recent ovulations |
|---|---|---|---|---|
| 'Hektoria' | 50 | 42 | 8 | 0·84 |
| 'New Sevilla' | 79 | 0 | 21 | 2·50 |
| 'Thorshammer' | 75 | 12·5 | 12·5 | 1·14 |
| 'Tafelberg' | 61·25 | 32·25 | 6·5 | 0·86 |
| Aggregate | 64 | 24 | 12 | 1·13 |

It is perhaps of interest to note in passing that the sample showing the highest rate of ovulation and the highest percentage of pregnancy came from the 'New Sevilla', which was working in the Weddell Area, while the other three came from the adjacent Bouvet Area. The point is mentioned because the number of ovulations may vary with whales from different regions or migrating from different breeding grounds. This is, however, the purest speculation.

The figures in the above table show that the average number of recent ovulations in each sample is mainly a function of the pregnant and resting whales, the whales which have recently ovulated without being fertilized forming a relatively insignificant class.

These results suggest, if there is enough material to be significant, that the increment of corpora lutea in a catch of whales in which the percentages of pregnant and resting whales are 50–79 per cent and 12–42 per cent respectively, as is true of most catches, is in the region of one per annum after the first adult season (when the average number is 1·91, see p. 246). The average number of recent ovulations for the whole of the mature material considered above is 1·13.

Corroboration of such figures is found when corpora lutea frequencies are dealt with in the next section. In order to apply this conclusion to the whole Antarctic stock, it is necessary to assume that the constitution of the population from which the catch is taken is consistent from year to year and that every year adults undergo roughly the same experiences at the breeding season.

The percentage of pregnant whales found in the Kerguelen Area, for which we have results for three seasons, may be taken as a rough indication that the same general state of affairs exists each year. The pregnant whales calculated as percentages of the resting and pregnant groups together were:

| | |
|---|---|
| 1932–3 ... ... ... | 61·0% |
| 1934–5 ... ... ... | 52·5% |
| 1935–6 ... ... ... | 58·4% |

It is not considered that the variation in these numbers is great enough to indicate that the experience of the breeding stock differs substantially from year to year. We may therefore be justified in applying the annual increment in corpora lutea suggested above to an estimate of the relation between age and corpora lutea numbers. It must be remembered, however, that the number of ova produced by an individual whale in the first breeding season may vary considerably (probably from one to seven). It is therefore very important to note that the age of any individual may not legitimately be determined from the number of its corpora lutea, but given a large number of whales with the same number of corpora lutea it should be possible to decide with some certainty the average age of the group (p. 262, fig. 13).

CORPORA LUTEA FREQUENCIES FOR TWO SEASONS. The collections of ovaries made in 1934–5 and 1935–6 were not of the same size: the first provided 547 pairs, the second 464. This is in both cases after deduction of the doubtful specimens mentioned above (p. 245) and damaged ovaries, some of which became detached from each other and from their labels. The results from the several ships have been combined according to the regions in which the ships were working at the time when the ovaries were collected, and appear in the table below. The immature whales are included here, but not in the corpora lutea frequency graphs nor in the percentage estimate of pregnancy.

The frequencies for the three areas in which the collections were made are shown graphically in Fig. 8. It will be seen that there is little consistency of outline between one area and another, that is to say maxima and minima do not fall to the same numbers in different areas. It may be that the age distribution of whales varies substantially from one area to another and that numbers of corpora lutea, indicating a rough age group, which are common in one area are lacking in another. Another and more likely explanation may be that the sample from each area is not big enough to eliminate chance fluctuations.

More consistent results are obtained by combining the frequencies from all the areas for each year. In order to make comparison between the two years easier, the frequencies are expressed as percentages of the total sample for the year and are shown graphically in Fig. 9. The frequency of each corpora lutea number is shown as a discrete point. The variation is so great that it has been thought best to make up a curve representing the

## 1934–5

| | | Numbers of corpora lutea | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Weddell Area | Pregnant | 7 | 5 | 1 | 1 | 8 | 7 | 5 | 7 | 6 | 3 | 2 | 3 |
| | Non-pregnant | — | 0 | 4 | 6 | 2 | 5 | 1 | 7 | 4 | 4 | 3 | 3 |
| Bouvet Area | Pregnant | 8 | 2 | 1 | 1 | 2 | 0 | 3 | 5 | 4 | 3 | 6 | 5 |
| | Non-pregnant | — | 4 | 4 | 5 | 3 | 4 | 1 | 1 | 0 | 0 | 1 | 1 |
| Kerguelen Area | Pregnant | 21 | 2 | 10 | 8 | 6 | 2 | 10 | 6 | 12 | 10 | 6 | 12 |
| | Non-pregnant | — | 7 | 11 | 8 | 4 | 4 | 6 | 6 | 9 | 11 | 5 | 5 |
| Total pregnant | | — | 9 | 12 | 10 | 16 | 9 | 18 | 18 | 22 | 16 | 14 | 20 |
| Total non-pregnant | | — | 11 | 19 | 19 | 9 | 13 | 8 | 14 | 13 | 15 | 9 | 9 |
| Grand total | | 36 | 20 | 31 | 29 | 25 | 22 | 26 | 32 | 35 | 31 | 23 | 29 |

| | | Numbers of corpora lutea | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Weddell Area | Pregnant | 6 | 3 | 2 | 1 | 1 | 3 | 3 | 2 | 1 | 3 | 1 | 1 |
| | Non-pregnant | 1 | 3 | 0 | 3 | 3 | 2 | 1 | 0 | 0 | 2 | 1 | 1 |
| Bouvet Area | Pregnant | 3 | 4 | 1 | 2 | 0 | 0 | 3 | 1 | 2 | 0 | 1 | 1 |
| | Non-pregnant | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 0 | 0 | 2 |
| Kerguelen Area | Pregnant | 11 | 7 | 6 | 8 | 6 | 1 | 5 | 10 | 4 | 4 | 4 | 4 |
| | Non-pregnant | 3 | 7 | 4 | 2 | 10 | 8 | 8 | 3 | 5 | 2 | 3 | 4 |
| Total pregnant | | 20 | 14 | 9 | 11 | 7 | 4 | 11 | 13 | 7 | 7 | 6 | 6 |
| Total non-pregnant | | 5 | 11 | 5 | 6 | 15 | 12 | 11 | 5 | 8 | 4 | 4 | 7 |
| Grand total | | 25 | 25 | 14 | 17 | 22 | 16 | 22 | 18 | 15 | 11 | 10 | 13 |

| | | Numbers of corpora lutea | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| Weddell Area | Pregnant | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Non-pregnant | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| Bouvet Area | Pregnant | 1 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| | Non-pregnant | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kerguelen Area | Pregnant | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | Non-pregnant | 2 | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 2 |
| Total pregnant | | 6 | 4 | 0 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 0 |
| Total non-pregnant | | 5 | 4 | 2 | 1 | 2 | 2 | 0 | 0 | 1 | 0 | 2 |
| Grand total | | 11 | 8 | 2 | 4 | 3 | 2 | 0 | 0 | 2 | 2 | 2 |

Total ovaries: pregnant 295, non-pregnant 252 (excluding those with 0 corpora) = 547.

1935–6

| | | Numbers of corpora lutea | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Weddell Area | Pregnant | 3 | 6 | 2 | 4 | 2 | 5 | 2 | 3 | 2 | 4 | 5 | 3 |
| | Non-pregnant | — | 1 | 2 | 1 | 2 | 3 | 4 | 2 | 0 | 0 | 1 | 0 |
| Bouvet Area | Pregnant | 37 | 10 | 11 | 7 | 10 | 10 | 6 | 12 | 8 | 9 | 13 | 10 |
| | Non-pregnant | — | 9 | 8 | 14 | 7 | 9 | 6 | 8 | 5 | 11 | 6 | 4 |
| Kerguelen Area | Pregnant | 5 | 3 | 5 | 0 | 0 | 2 | 4 | 3 | 3 | 3 | 3 | 0 |
| | Non-pregnant | — | 3 | 0 | 0 | 1 | 0 | 4 | 0 | 1 | 5 | 2 | 1 |
| Total pregnant | | — | 19 | 18 | 11 | 12 | 17 | 12 | 18 | 13 | 16 | 21 | 13 |
| Total non-pregnant | | — | 13 | 10 | 15 | 10 | 12 | 14 | 10 | 6 | 16 | 9 | 5 |
| Grand total | | 45 | 32 | 28 | 26 | 22 | 29 | 26 | 28 | 19 | 32 | 30 | 18 |

| | | Numbers of corpora lutea | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Weddell Area | Pregnant | 1 | 1 | 3 | 2 | 0 | 1 | 5 | 0 | 1 | 2 | 0 | 1 |
| | Non-pregnant | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bouvet Area | Pregnant | 11 | 11 | 5 | 3 | 6 | 6 | 4 | 2 | 5 | 6 | 4 | 3 |
| | Non-pregnant | 3 | 1 | 3 | 4 | 1 | 6 | 1 | 4 | 4 | 3 | 1 | 1 |
| Kerguelen Area | Pregnant | 4 | 4 | 0 | 1 | 3 | 2 | 4 | 2 | 0 | 0 | 1 | 0 |
| | Non-pregnant | 1 | 2 | 0 | 2 | 6 | 1 | 1 | 1 | 2 | 0 | 0 | 0 |
| Total pregnant | | 16 | 16 | 8 | 6 | 9 | 9 | 13 | 4 | 6 | 8 | 5 | 4 |
| Total non-pregnant | | 4 | 3 | 3 | 7 | 7 | 8 | 2 | 5 | 6 | 3 | 1 | 1 |
| Grand total | | 20 | 19 | 11 | 13 | 16 | 17 | 15 | 9 | 12 | 11 | 6 | 5 |

| | | Numbers of corpora lutea | | | | |
|---|---|---|---|---|---|---|
| | | 24 | 25 | 26 | 27 | 28 |
| Weddell Area | Pregnant | 1 | 0 | 0 | 0 | 1 |
| | Non-pregnant | 1 | 0 | 0 | 0 | 0 |
| Bouvet Area | Pregnant | 2 | 0 | 2 | 2 | 0 |
| | Non-pregnant | 1 | 2 | 0 | 2 | 1 |
| Kerguelen Area | Pregnant | 0 | 1 | 1 | 0 | 0 |
| | Non-pregnant | 1 | 2 | 0 | 0 | 0 |
| Total pregnant | | 3 | 1 | 3 | 2 | 1 |
| Total non-pregnant | | 3 | 4 | 0 | 2 | 1 |
| Grand total | | 6 | 5 | 3 | 4 | 2 |

Total ovaries: pregnant 284, non-pregnant 180 (excluding those with no corpora) = 464.

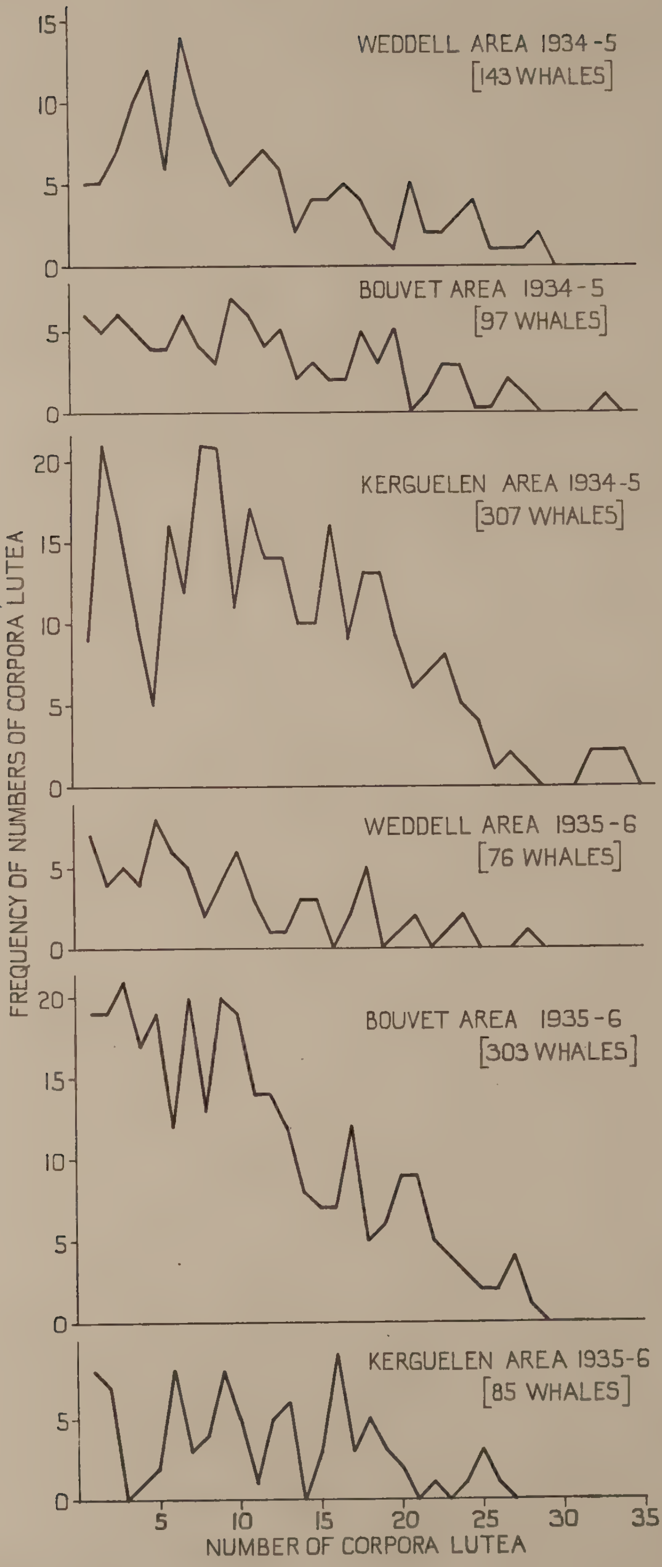


Fig. 8. Frequency of numbers of corpora lutea, 1934–5 and 1935–6.

general trend of frequencies. The method adopted was to take the frequencies in groups of three, add them together, and obtain the mean. For instance, the number of occurrences of one, two, and three corpora lutea were added together and divided by three. Then the numbers for two, three, and four; three, four, and five, were treated in the same way, and so on. Each frequency comes into the calculations thrice and a considerable smoothing effect is obtained, which eliminates the fluctuations due to faulty sampling and possible individual variations while preserving the real trend of the frequencies. Only those ovaries with one or more corpora lutea have been included, since this part of the discussion is confined to definitely mature whales.

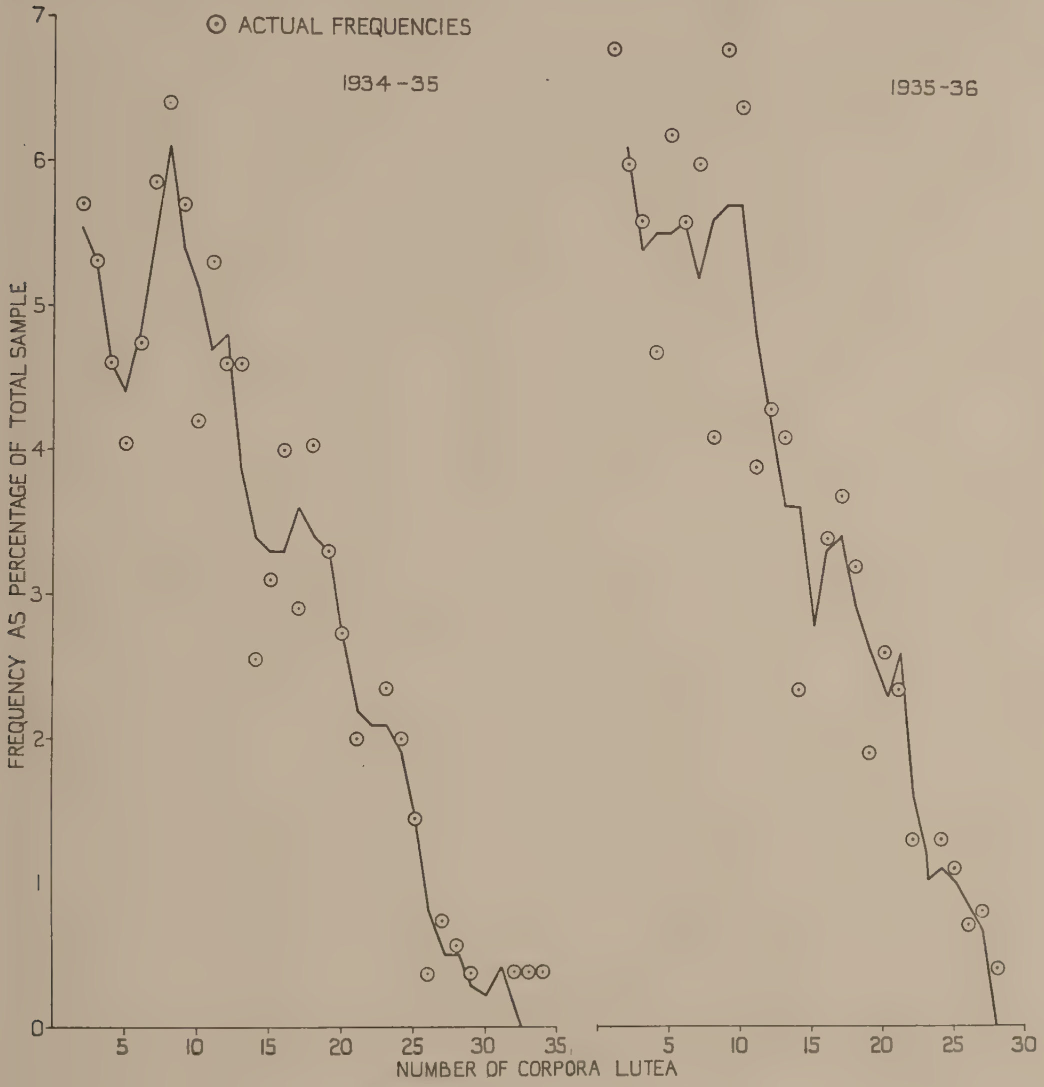


Fig. 9. Smoothed corpora lutea frequencies, aggregate, 1934–5 and 1935–6.

SIMILARITY OF FREQUENCIES. In spite of the fact that the proportions of ovaries from the different regions are not the same for the two years, it will be seen that the curves are substantially of the same shape.

HOMOGENEITY OF ADULT CATCH. The close similarity of the two frequency curves can hardly be a coincidence. In the season 1934–5 the majority of the ovaries were taken in the Kerguelen Area, whereas in 1935–6 those from the Bouvet Area predominated. There are points of similarity between these two groups of material. The smaller collections from the other areas are probably too small to show any definite features, but added to the main collection they contribute to the great similarity of the total samples of ovaries for the two seasons. The fact that smoothing of the aggregate corpora lutea frequency curves is necessary in order to bring out their similarity of contour and gradient is in itself evidence that the collections of ovaries could with advantage have been two or three times as large. In view of the practical difficulties of obtaining and examining such a large collection we must be content with the numbers available, which after legitimate manipulation show striking similarity in the two seasons. The results suggest that the age composition of the Antarctic Blue female population from which the catch is drawn is similar in all the widely different regions from which this material was taken. It would then appear that one area does not harbour a particular age of whales and the adult population is approximately homogeneous in character and is freely distributed over the whole of the Antarctic whaling grounds from about 58° S to the edge of the pack and about 30° W to 100° E, these being the geographical limits of these collections.

This conclusion, tentative as it must be, may or may not be confirmed by the results from a further collection of ovaries now being made (season of 1936–7). In any case it may be held to apply only to the adult portion of the population, and the possibility that immature whales follow definite migratory routes from the tropics to the Antarctic and tend to be concentrated in certain regions of the latter is by no means ruled out. It is hoped that information on this point will be gleaned from an examination of length frequencies of whales taken in pelagic whaling in the near future.

It will be seen that there are certain fairly conspicuous peaks and abysses in the two curves in Fig. 9, which since they withstand smoothing are probably of some significance. In Fig. 10 the two curves are shown together, and it is interesting to note that with one or two minor exceptions there seems to be some relation between the peaks and depressions. The points thought to be related are marked *A*, *A'*; *B*, *B'*, etc.

Evidence has been adduced above (pp. 246–50) that an average of rather more than one corpus luteum is added to the ovaries of the Antarctic adult stock in one year, and some confirmation of this is to be found in Fig. 11. If the two curves are taken to represent the same stock of whales in two successive seasons the peak, for example at eight corpora lutea in the 1934–5 curve (marked *B* in the figure), should reappear in the curve for 1935–6 at between nine and ten corpora lutea, and it will be seen that in fact it does so at *B'*. *A* and *A'* do not fit so well. The increment indicated by the relation of *A'* to *A* is two corpora lutea. The curves do not agree so well in contour over this part. (Curiously enough an almost perfect agreement of contour and an increment from *A* to

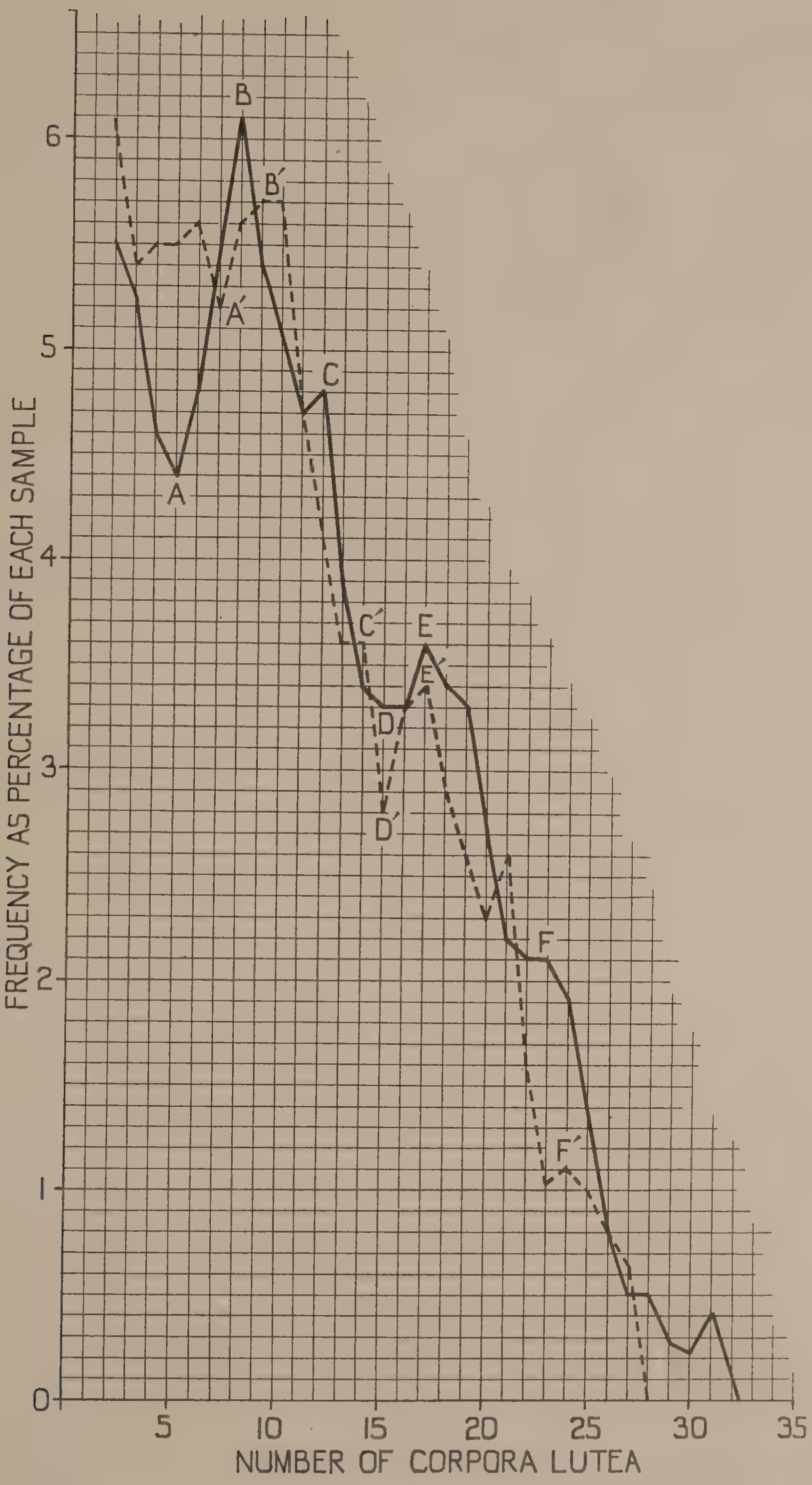


Fig. 10. Corpora lutea frequencies for two seasons superimposed (solid line, 1934–5; pecked line, 1935–6).

*A′* is obtained by eliminating from the material all ovaries which came from whales 78–81 ft. long, and which contained more than *four* corpora lutea. It will be recalled that the data were originally trimmed in the light of personal experience to exclude all whales purporting to be 78–81 ft. long and showing more than *seven* corpora lutea. It may be that an allowance of up to seven corpora lutea in the first breeding season was on the generous side, and that the whale which I found in 1932–3 with seven corpora lutea (length 81 ft.) was really an exceptional whale.) Point *C* at twelve corpora lutea might well be represented at *C′* a year later with thirteen to fourteen corpora lutea. Possibly owing to small numbers there are unexplained features in the rest of the curve. *D* and *E* seem to have stood still at *D′*, *E′*, but *F* might be reflected in *F′*. The vertical interval between the related points would of course bear some relation to the mortality in one year.

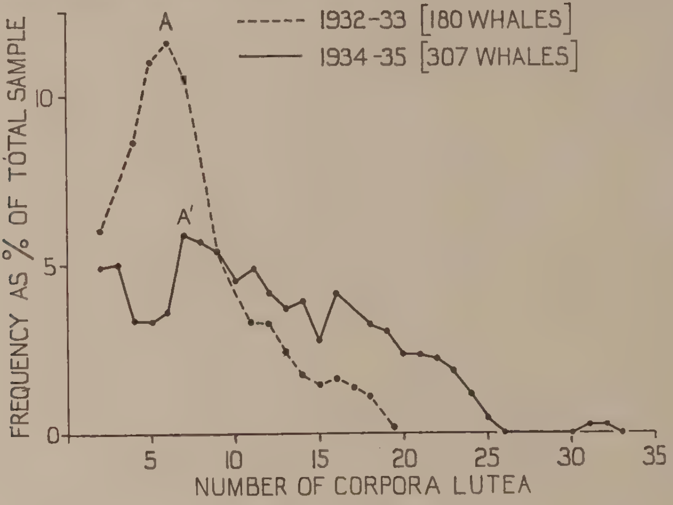


Fig. 11. Smoothed corpora lutea frequencies, Kerguelen Area, 1932–3 and 1934–5.

There is thus some indication that the increment of corpora lutea in one year is slightly over one, but probably not as much as one and a half. The progression seems to apply to all ages of adults after the first sexual season. If it did not there would be a piling up of frequencies at the number of corpora lutea at which sexual activity ceased.

One set of figures is available for considering the effect of a two-year interval. The small collection which I made in 1932–3 (180 ovaries) in the Kerguelen Area yields the smoothed frequency curve shown in Fig. 11. For comparison is shown also the smoothed frequencies for the same area from the data collected in 1934–5 (307 specimens). The pronounced maximum in 1932–3 comes actually at six corpora lutea, but from consideration of the neighbouring frequencies the maximum may be set somewhere between five and six; the sample is too small for absolute accuracy. Two years later the maximum has moved to between seven and eight. Here again at the risk of hair-splitting, one may say that the maximum is nearer eight than seven. The movement of the peak can be said to be slightly over two, so that whales in this area, so far as can be determined from the small samples available, appear to have added slightly more than two corpora lutea in two years. This is in agreement with the results from the two large collections one year apart with which we have just dealt. In the biological notes above attention was drawn to the apparent failure of Wheeler's method for Fin whales when applied to Blue whales. If the foregoing calculations are accepted an explanation of this failure is easy. If the increment of corpora lutea is in the region of one per annum, instead of several as in Fin whales, it is naturally impossible for the majority of whales to add a number of corpora lutea which will stand out as peaks in a frequency graph.

AGE AND CORPORA LUTEA (SUMMARY). Three lines of approach have been explored in the quest for a relation between age and number of corpora lutea:

(1) It has been shown that the number of ovulations found in whales which had not long since attained to maturity and which appeared to form an age group by themselves averaged 1·91. This figure is taken to be the average number of ovulations in the first breeding season.

(2) The subsequent rate of increase in one season measured by the number of recent ovulations is 1·13, less than the first season but apparently consistent throughout the adult life of the whale. The numbers of recent corpora lutea in ovaries which have many old ones show that the tendency to ovulate is not absent from those whales which may be said to be of advanced age.

(3) The progress of peaks in the frequency curves indicates an increase of slightly over one corpus luteum per year. As was shown in the argument leading to the result expressed in (2) above, the increment depends to some extent on the percentage of whales which have not ovulated in the breeding season prior to capture. It will probably not be far short of the mark if we say that for every ten years of adult life after the first Blue females produce eleven corpora lutea.

It must be borne in mind that there are factors which may alter the proportions of pregnant, resting, and ovulating whales, and that no positive proof can be advanced for the conclusion that an average of one and a fraction corpora lutea are added every year after the first adult season. In spite of these difficulties, an attempt will be made to apply this conclusion, and the justification of such an attempt must lie in the importance of the deductions to be made, even if they do no more than approximate to the truth. It is indeed unlikely that any sample of biological material gathered from animals of such wide distribution and imperfectly understood habits will ever yield completely consistent results. In any case, it seems important to advance any deductions that can be made from the material as soon as possible (pp. 261 *et seq.*).

## THE AGE AT PHYSICAL MATURITY

A remarkably close correlation was observed between the number of corpora lutea and the onset of physical maturity. The occurrence of physical maturity was seen to coincide with the presence of eleven to twelve corpora lutea. The closeness of the correlation shows that whatever the potential variation in the numbers of corpora lutea added in each breeding season, the average number is fairly constant. Converting the number of corpora lutea into an indication of age, it appears that physical maturity takes place at ten to eleven years of age (i.e. 1·91 corpora lutea accumulated in third year from birth plus eight years at an average increment of 1·13 per annum). Wheeler (1930) found the age of Fin whales at physical maturity to be between six and eight years (p. 417). Blue whales would appear to take rather longer to reach maturity, which seems reasonable since they grow to greater lengths than Fin whales.

The determination of the age of Blue females at physical maturity is of great importance from the economic point of view, since the data to be derived from this could not fail to be of assistance in assessing the age composition of the catch. It would not be impossible for a simple examination of the thoracic vertebrae to be carried out by whalers during the dismemberment of the whales. The data resulting from this examination would be a guide only to the number of whales in the catch which were past complete physical maturity, and would not furnish a complete age distribution. The results would however be valuable in the study of the composition of the catch through several successive years.

## PRESENT SPAN OF LIFE

As shown above we have no data which will indicate the age of the very oldest whale which might live in the sea under normal conditions. One is justified in referring to the present situation as abnormal if only because of the very high proportion of immature whales taken (p. 266). While it would be of great interest to know how long a Blue female can live, because of the widespread conjecture there has been on the subject, it is perhaps not essential so long as we know the greatest age to which whales retain their reproductive powers. The percentage of pregnant whales for the two seasons is shown in the following table:

| | Number of corpora lutea | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1934–5 | 45 | 39 | 35 | 64 | 41 | 69 | 56 | 63 | 50 | 61 | 69 | 80 |
| 1935–6 | 59 | 64 | 43 | 54 | 58 | 46 | 64 | 68 | 50 | 70 | 72 | 80 |

| | Number of corpora lutea | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1934–5 | 56 | 64 | 65 | 32 | 25 | 50 | 72 | 44 | 64 | 60 | 46 | 54 |
| 1935–6 | 84 | 73 | 46 | 56 | 53 | 86 | 44 | 50 | 73 | 83 | 80 | 54 |

| | Number of corpora lutea | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | |
| 1934–5 | 50 | 0 | 25 | 33 | 0 | — | — | 50 | (100) | 0 | |
| 1935–6 | 25 | 100 | 50 | 50 | — | — | — | — | — | — | |

0 means 0%, — means no data.

The oldest surviving whales were of the order of thirty years old, if the foregoing evidence is accepted, and were found to be sexually active. Four whales were thirty years old or over, and two of these were pregnant. There appears to be no diminution in fertility with increasing age so far as the small number of specimens available in the later stages show. These whales show no climacteric. The life line comes down so abruptly to this age that it is quite possible that intensive whaling has substantially shortened the life span, so that even the oldest reproducing whales might live longer if undisturbed.

## POPULATION AND RECRUITMENT

The constitution of the adult catch is of the greatest interest, since by examination of this data we may be able to glean some information as to the present condition of the whale population and by inference therefrom make some prognosis.

I have discussed the age distribution of the whales in the material for 1934–5 and 1935–6 with Mr Edser.

The correlation between corpora lutea numbers and age enables us to use the corpora lutea frequency curves to represent an age distribution of the adult catch. The frequency curves then may be used as an adult census in a very approximate sense, though the fact that the curves agree so well in their contours is strongly suggestive of the sufficiency of the sample in each case as a basis for estimating the age distribution of the adults.

The age distribution of the catch may itself be applied to an estimate of the age distribution of the adult population in Antarctic waters but only on the condition that the whales caught are a genuine sample of the whales in the sea. In other words it is possible to form an estimate of the population provided that all ages of whales are taken impartially by the whalers. Whalers cannot of course guess the age of the whales they are pursuing, and the question must be transferred to considering whether all lengths of adults are taken impartially, since if all lengths are taken all ages must be also.

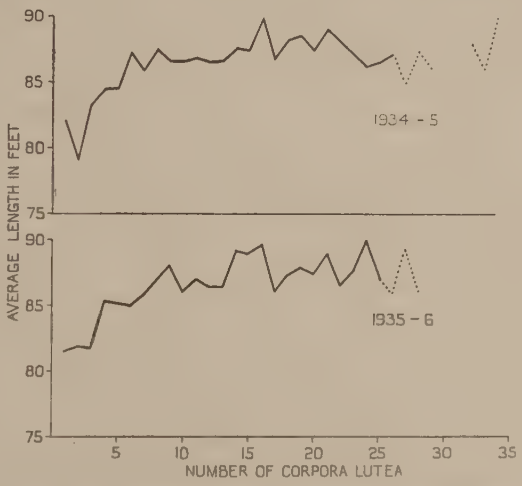


Fig. 12. Average length of whales in each class of corpora lutea numbers.

The average length of whales found in each class of corpora lutea numbers was shown for the 1932–3 material (Fig. 6). Since the point at issue is an important one it would be as well to supplement this material with figures from the 1934–5 and 1935–6 data (Fig. 12). The average length in the first four groups is low but increasing with age and rises to 85 ft. by the time five corpora lutea have been accumulated, remaining between 85 and 90 ft. throughout the whole of the rest of life.

It would appear from these figures that whales with anything up to four corpora lutea are definitely smaller than their fellows and might therefore be less liable to attack, although it is questionable whether a gunner can readily discriminate between a whale of 80 ft. and one of, say, 85 ft. The former, being newly mature, have not had time to calve, so that none of them will be absent from the catch through being protected while in lactation. It is therefore probable that the youngest adults are over-represented on the whaling grounds. This will go far to offset any tendency that whalers might have to discriminate against them.

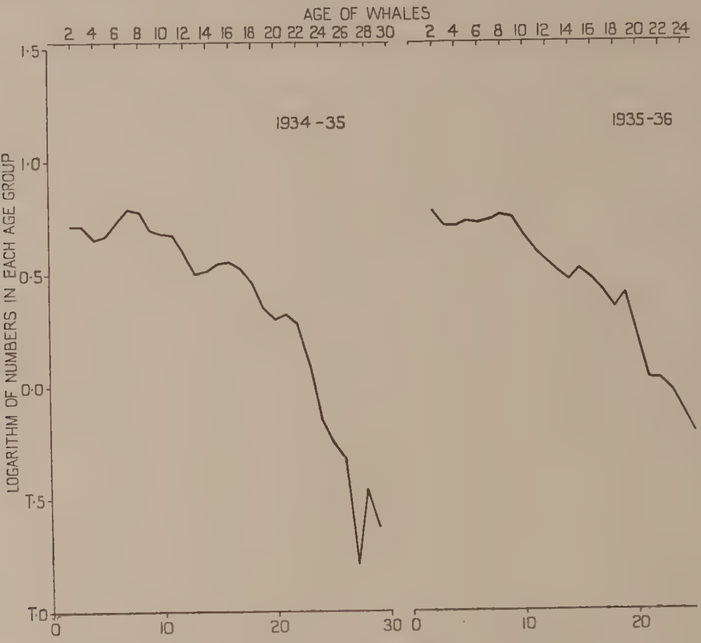


Fig. 13. Logarithmic age distribution of adults.

It is probable therefore that all ages of mature whales are taken in proportion to their presence on the whaling grounds and that the age distributions which we are considering may be taken to be a random sample of the Antarctic population.

In a constant animal population under natural conditions the rate of recruitment by births must be just sufficient to balance the mortality at various stages in the life history. If we assumed that a constant stock was subject to constant birth and death rates, the number of living in year groups would take the form of a decreasing geometrical progression. The age distribution of such a population, expressed graphically with the numbers of animals in each age group given in logarithms, is represented by a straight line. The gradient of the line from the beginning of life to the end is an indication of the mortality from various causes.

We cannot say that the stock of whales has ever been exactly in accordance with the assumptions made above, but it may be argued that over long periods of pre-whaling history the stock must have shown approximate constancy, as otherwise it would have faded to extinction or grown to such enormous proportions as to have gained historic notice. Furthermore we do not know that the incidence of the natural death rate is constant at all ages, but analogy with other species gives us some ground for the belief that mortality is roughly constant between adolescence and the onset of senescence.

In the present instance adults only are being considered, and the age distribution of adults indicated by the number of corpora lutea has been shown above (Fig. 9). The actual numbers in each age class for the seasons 1934–5 and 1935–6 have been replaced by the logarithms of these numbers in Fig. 13. If we consider these graphs in terms of the principles advanced above, the most obvious feature is that the age distribution does not fall on a straight line. It would appear therefore that the population from which these samples were taken is very far from being a natural one. It is difficult to find any explanation for this except on the grounds that the stock is being affected by hunting.

It is impossible to say where a line representing a static population would lie in relation to the existing curves. Supposing however we assume that it lies along the line *A–A′* in Fig. 14, in which the two logarithmic curves of Fig. 13 have been amalgamated. This line does lie along a part of the curve which approximates to a straight line, and which may conceivably be taken to represent what is left of a stock of whales which lived under natural conditions. The shape of the left part of the curve with relation to the straight line would indicate a heavy reduction in the number of young adults. If on the other hand the natural line should lie in the position *B–B′* the indication would be of an unnatural reduction in the number of the older whales. The latter position for the line seems improbable since the gradient is so slight as to lead to the corollary that whales under natural conditions should live to be well over seventy years of age. If this were true, an occasional specimen would in all likelihood have appeared in these collections with an age of at least forty years.

It may be argued then that the line *A–A′* in Fig. 14 is more likely to be an indicator of the constitution of a natural population. If we could be certain of this it might be possible to calculate the date at which whaling first began to take effect on the composition of the adult stock, but this would lead us too far into the realms of speculation. All that can be said with some degree of certainty is that a substantial reduction in the adult stock has been caused, most probably among the younger whales.

The influence of the killing of adults is twofold. Firstly, the stock is diminished by the actual numbers taken. Secondly, and more important, the taking of female adults diminishes the breeding potentialities of the stock and hence causes a decline in future recruitment. The loss is greater or less according to the expectation of life which each adult had at the time of its capture. If it were possible for only the oldest females to be taken, the loss to the future stock would be slight, since these whales would have contributed most of their quota of young. But if the killing applies to all ages and is excessive the inevitable result will be a decline in recruitment.

It is important to note that the effect of whaling would be cumulative, since adults killed are a loss in terms of future recruitment as well as a diminution of the actual stock. Continued whaling can therefore mean only a continued diminution of the breeding

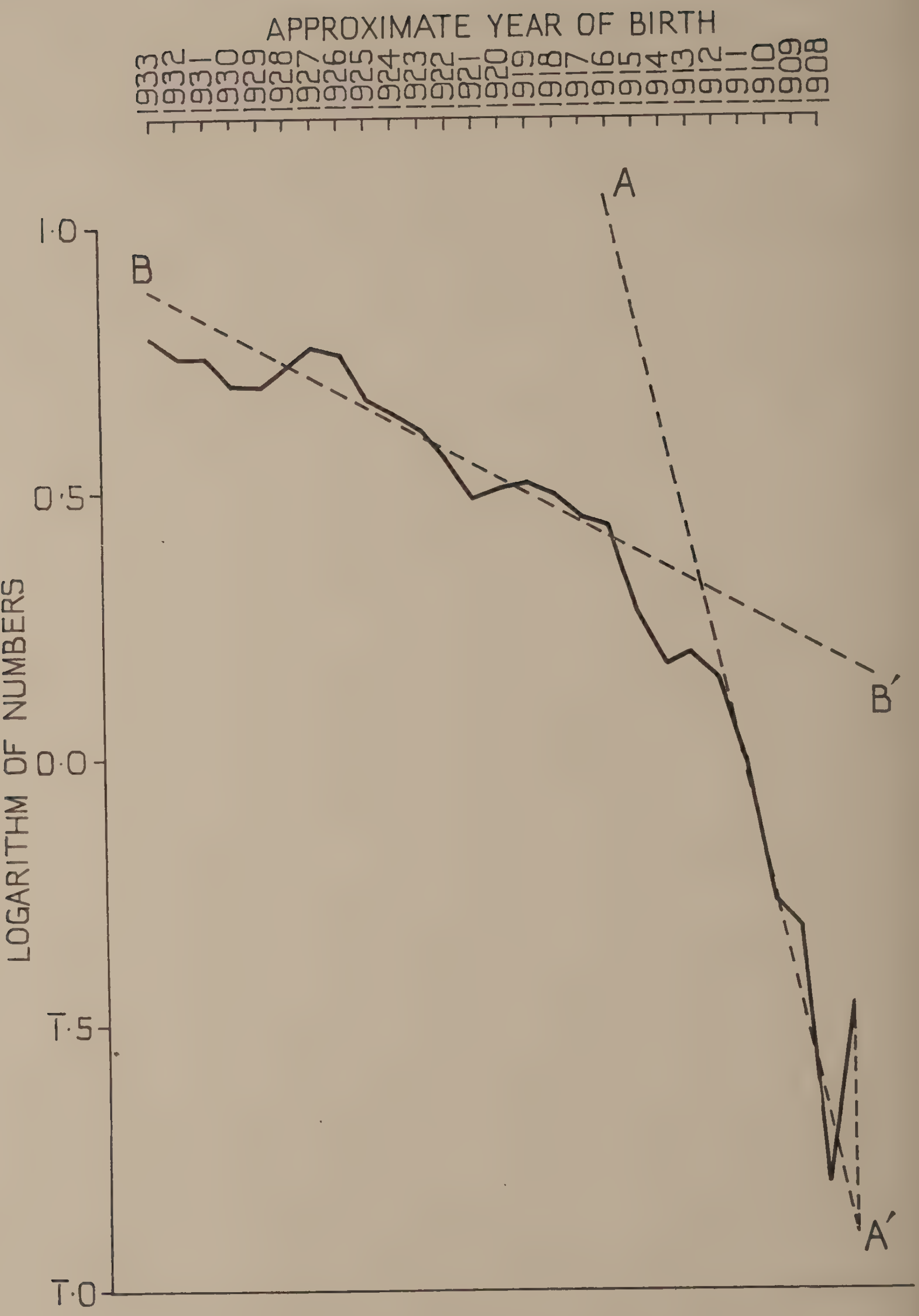


Fig. 14. Composite age distribution, logarithmic.

stock. Ultimately the population may be so reduced as to make recovery impossible or at best very slow.

The number of Blue whales taken in Antarctic whaling, including South Georgia, since the beginning, as far as known, are given in a list in Appendix I.

## AVERAGE LENGTH OF BLUE FEMALES

Hjort, Ruud and Lie have, in their analyses of the pelagic catch for the last five years, computed the average length of whales taken. The following table is from *Hvalrådets Skrifter*, No. 14, p. 28:

| Season | Total whales considered | Mature: average lengths | | Immature: average lengths | |
|---|---|---|---|---|---|
| | | F. | M. | F. | M. |
| 1930–1 | 18,452 | 84·0 | 80·3 | 72·6 | 70·5 |
| 1932–3 | 10,815 | 84·4 | 80·2 | 71·9 | 70·0 |
| 1933–4 | 14,082 | 84·5 | 80·2 | 73·2 | 70·9 |
| 1934–5 | 15,444 | 84·6 | 80·2 | 72·0 | 70·1 |
| 1935–6 | 16,036 | 84·0 | 79·6 | 72·0 | 70·3 |

The writers say: "This summary shows that the average length in each group is practically the same for four seasons.... But there is no real evidence of any continuous decline in the average length either of mature or immature animals" (No. 12, p. 24).

Prior to this table the authors have drawn attention to a general principle that "all experience gained in fishery and whaling investigations goes to prove that the influence of fishing or whaling operations upon the stock first becomes noticeable in a reduction of the size of the older animals" (*loc. cit.*, p. 22).

In a note to *Nature* (1936) I drew attention to a fallacy underlying this presentation of mean lengths. The authors have divided the whales taken into two categories, mature and immature, and calculated the mean length of the whales in each. The possible effect of whaling is therefore masked, since no account is taken of the proportion of mature and immature whales in the catch.

I have calculated the average length of the whole catch of females in each of the above five seasons without dividing them into mature and immature classes. The necessary data has been culled from the *Hvalrådets Skrifter*, so that the basis of argument is the same as that of Hjort, Ruud and Lie. The average lengths are shown in the following table:

| Season | Average length (ft.) |
|---|---|
| 1930–1 | 82·36 |
| 1932–3 | 81·97 |
| 1933–4 | 81·85 |
| 1934–5 | 79·88 |
| 1935–6 | 78·99 |

It will be seen that the average length falls off year by year with a particularly sharp drop of nearly 2 ft. in 1934–5.

Not only has the average length of the catch fallen, but it has reached a critical point. It has been shown that apparently newly mature whales appear in the Antarctic catch at lengths of 78–81 ft. The whales taken in 1934–5 averaged just about the mean of these lengths. On the whole, then, Blue females taken in 1934–5 were newly mature. Not having had time to reproduce, they were killed at the outset of their reproductive careers. Actually, of course, the catch is composed of mature and immature whales, but the relative quantities are such that the net result is as described above.

I wish to repeat the warning I gave in *Nature* that the consequences of continued intensive fishing under these conditions cannot fail to have a disastrous effect on the future of the stock. When killing has reached the point at which recruitment, already dangerously reduced, shall have virtually ceased, one may say that the future of Blue whaling will be limited to the lifetime of those whales now surviving.

## INCREASE OF IMMATURE WHALES IN THE CATCH

Intimately bound up with the decline in average length of the female catch is the rise in the percentage of immature whales in the catch. For this we rely again on the figures given in *Hvalrådets Skrifter* (No. 12, p. 20). The results have been expressed there for the last five seasons in terms of the total Blue catch, that is to say the immature females are shown as a function of the total catch, male and female.

| Season | Total whales considered | Percentage of immature females |
|---|---|---|
| 1930–1 | 18,452 | 6·8 |
| 1932–3 | 10,815 | 10·6 |
| 1933–4 | 14,082 | 10·6 |
| 1934–5 | 15,444 | 17·5 |
| 1935–6 | 16,036 | 19·0 |

It is, I think, better to take the immature component of each sex as a function of the total animals of that sex. I have, therefore, taken the immature females as percentages of the female catch in each year, and the results are shown in the following table:

| Season | Percentage of immature females |
|---|---|
| 1930–1 | 15·16 |
| 1932–3 | 21·45 |
| 1933–4 | 22·93 |
| 1934–5 | 37·23 |
| 1935–6 | 41·67 |

The tables above show that the rise in the percentage of immature females in the catch has been very considerable and has more than doubled itself in four years.

In the issue of *Hvalrådets Skrifter* from which these figures were taken, the authors suggest that the rise in the number of immatures in 1934–5 is due to some extent to the time limit and later season. In this year for the first time the Norwegian and most of the British fleet did not start fishing till the beginning of December instead of in October as normally in the past. There may be a tendency for more immature whales to be killed in the latter half of the season, as their data go to show, but it is extremely doubtful whether the shifting of the centre of gravity of the season could produce such a marked difference as shown above.

Not only is the rise in immature captures a sign of depletion of the stock, but the practice of taking any immatures at all must be deprecated, since future breeders are being removed from the stock before they have reproduced. The decline in the recruitment of the adult stock which was discussed in a previous section (pp. 261–5) will have been greatly accelerated in late years by the killing of immatures. Killing of adults, as has been said, reduces the birth rate, in any case, and if those whales that do succeed in being born are intercepted before they reach maturity the recruitment is bound to decline even further.

## SUMMARY

1. Investigation into the life history of Antarctic Blue whales has been made both by personal examination of Blue whales taken in pelagic whaling and by inspection of ovaries imported from the southernmost whaling grounds. Use has been made of statistics supplied by the factory ships sending ovaries and of summarized statistics prepared by Norwegian writers on the subject. Material collected at South Georgia and Saldanha Bay from 1925–31 by the staff of the Discovery Investigations has also been utilized.

2. The conditions of modern pelagic whaling are shortly reviewed in so far as they affect the composition of the catch on which conclusions may be based.

3. There seems every reason to believe that Blue whales taken by the pelagic factories in the Weddell, Bouvet and Kerguelen Areas are identical in species and reproductive habits with those taken at South Georgia and off the African coast. Sexual maturity appears to be attained at the same age and length, and the pairing season and period of gestation seem to be identical.

4. The onset of physical maturity in Blue females coincides with the accumulation of eleven corpora lutea in the ovaries. Length above 81 ft. is in general no guide to age. Blue females become physically mature at a minimum length of 86 ft., though many grow much beyond this length.

5. Detailed inspection of the percentage of pregnant and resting whales taken in pelagic whaling and at South Georgia and Saldanha Bay suggests that while Blue whales can breed once every two years at best, a substantial proportion of the adult

stock may breed once in three years. A possible mean figure of once in two and a half years is suggested.

6. The annual increment of corpora lutea in the ovaries of the whole adult catch is discussed. Whales from 78 to 81 ft., a group which there is reason to suppose is a year group of newly mature whales, are found with an average of 1·91 corpora lutea. There is evidence that in subsequent years the increment is 1·13.

7. The corpora lutea frequencies furnish indications which support paragraph 6. Prominent features of the graph of frequencies are found to move up by slightly more than one corpus luteum in one year and proportionally in two years.

8. A tentative correlation between age and number of corpora lutea is thus established. The results suggest that whales over two and under three years old are found with two corpora lutea; subsequently there is an increase of eleven corpora lutea for every ten years.

9. There is evidence which suggests the homogeneity of the adult female population all over the present pelagic whaling grounds.

10. Physical maturity will thus be attained at ten to eleven years of age.

11. The oldest females taken (1934), regarded as of the order of thirty years of age, show no sign of diminishing fertility, possibly because under present conditions Blue females are unable to survive long enough to reach a climacteric.

12. Examination of the age distribution of the population of adult Blue females suggests that there has been a progressive diminution in the rate of recruitment of recent years. The present rate is thought to be insufficient to maintain the stock of Blue whales under the present intensity of whaling operations.

13. The method of presenting average lengths adopted by Hjort, Lie and Ruud in *Hvalrådets Skrifter* is criticized. In a revised form the average lengths of females taken in the last five years has fallen from 82·36 (1930–1) to 78·99 ft. (1935–6). Blue females are thus caught on the average before they have had time to reproduce at all.

14. Another aspect of the situation described in 13 above is the increase in immature whales caught. This again is shown in a revised form preferred to the Norwegian presentation. Over 41 per cent of the total catch of females in 1935–6 consisted of immatures.

15. The evidence above all points to the acute hardship which is being suffered by the stock of Antarctic Blue whales. The stock is already seriously depleted and further hunting on the same scale bids fair to make Blue whales so scarce that they will cease to be a source of profit to the industry and so diminished in numbers that the stock even if completely protected may take many years to recover.

## LITERATURE CITED

BARRETT-HAMILTON, G. E. H. *See* HINTON, M. A. C.

CALLOW, R. K., LAURIE, A. H. and PARKES, A. S., 1935. *The Corpus Luteum of the Whale as a Source of Progestin.* J. Soc. Chem. Industr., LIV, No. 47, "Chemistry and Industry", p. 1025.

HARMER, S. F., 1929. *Southern Whaling.* Proc. Linn. Soc. Lond., pp. 85–163.

HART, T. JOHN, 1935. *On the Diatoms of the Skin Film of Whales and their possible bearing on Problems of Whale Movements.* Discovery Reports, X, pp. 247–82, pl. XI.

HINTON, M. A. C., 1925. *Report on the Papers Left by the Late Major Barrett-Hamilton, Relating to the Whales of South Georgia.* Crown Agents for the Colonies. London, pp. 57–209.

HJORT, J., JAHN, G. and RISTING, S. See *International Whaling Statistics.*

HJORT, J., LIE, J. and RUUD, T., 1932–5. *Norwegian Pelagic Whaling in the Antarctic.* Hvalrådets Skrifter, Nos. 3, 7, 8, 9, 12 and 14. Oslo.

*International Whaling Statistics.* Edited by the Committee for Whaling Statistics Appointed by the Norwegian Government: vols. I–VI. Oslo, 1930–5.

LAURIE, ALEC H., 1936. *The Stock of Antarctic Blue Whales.* Nature, CXXXVIII, p. 33.

MACKINTOSH, N. A. and WHEELER, J. F. G., 1929. *Southern Blue and Fin Whales.* Discovery Reports, I, pp. 257–540, pls. XXV–XLIV, text-figs. 1–157.

MARSHALL, E. H., 1930. *Report on a Visit to the Ross Dependency.* Geogr. J., LXXV, No. 3.

WHEELER, J. F. G., 1930. *The Age of Fin Whales at Physical Maturity.* Discovery Reports, II, pp. 403–34, pl. V, text-figs. 1–5.

—— 1934. *On the Stock of Whales at South Georgia.* Discovery Reports, IX, pp. 351–72, text-figs. 1–3.

# APPENDIX I

## BLUE WHALES TAKEN IN THE ANTARCTIC SINCE 1904–5 AND OFF THE COAST OF AFRICA SINCE 1910

These figures are taken from *International Whaling Statistics*. Since the investigations of Mackintosh and Wheeler at Saldanha Bay (1925) and those of Ommanney and Laurie at Durban (1930) it has been held reasonable to consider the whales taken off the African coasts as being of the same general stock as those taken in the Antarctic. The high percentage of immature whales taken off Africa makes, as Mackintosh and Wheeler point out (p. 467), this fishery proportionately more destructive than the more southerly fisheries. The killing of whales off Africa may therefore be considered for all their relatively small numbers as an important contributory cause in such diminution as the stock of Blue whales may have suffered.

Figures for the Antarctic catch include South Georgia, South Shetlands, South Orkneys, and all pelagic whaling.

*Blue Whales taken* 1904–36

| Season | Antarctic catch | African catch[1] | Season | Antarctic catch | African catch[1] |
|---|---|---|---|---|---|
| 1904–05 | 11 | — | 1920–21 | 2617 | 248 |
| 1905–06 | 51 | — | 1921–22 | 4416 | 695 |
| 1906–07 | 22 | — | 1922–23 | 5683 | 1074 |
| 1907–08 | 4 | — | 1923–24 | 3732 | 903 |
| 1908–09 | 253 | — | 1924–25 | 5703 | 1388 |
| 1909–10 | 176 | 2 | 1925–26 | 4697 | 1744 |
| 1910–11 | 393 | — | 1926–27 | 6545 | 1743 |
| 1911–12 | 1109 | 24 | 1927–28 | 8334 | 1004 |
| 1912–13 | 2193 | 59 | 1928–29 | 12734 | 727 |
| 1913–14 | 2334 | 285 | 1929–30 | 17487 | 958 |
| 1914–15 | 4203 | 79 | 1930–31 | 29410 | 122 |
| 1915–16 | 4871 | 264 | 1931–32 | 6488 | 109 |
| 1916–17 | 3820 | 373 | 1932–33 | 18891 | 85 |
| 1917–18 | 2268 | 136 | 1933–34 | 17349 | 71 |
| 1918–19 | 1801 | 120 | 1934–35 | 15858[2] | ? |
| 1919–20 | 1874 | 215 | 1935–36 | 16528[3] | ? |

[1] Taken in southern winter of the second year of each pair.

[2] From *Hvalrådets Skrifter*, No. 12, p. 18.

[3] From *Hvalrådets Skrifter*, No. 14, p. 21.

# APPENDIX II

## PARTICULARS OF THE COLLECTIONS OF OVARIES, 1934–6

In the tables given below the ovaries received from Antarctic whaling grounds are listed according to the ships which sent them. The tables give the serial number of each pair of ovaries, the date when it was taken, the ship's position at the time, length of the whale from which it came in English feet (whenever available), and the number of corpora lutea found. When the corpora lutea number is printed in italics it indicates that pregnancy with one foetus is shown by the corpora; when printed in clarendon it indicates twins. A dash (—) means that the ovaries were missing when the barrel was opened, or that the ovaries had become separated, and detached from the label, or were too damaged and decomposed to be used.

## 1934–5

### *Fl.F. ‘Southern Princess’*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|
| | 1934 | | | |
| 1 | Oct. 22 | 57° 08′ S, 83° 48′ E | 89 | 11 |
| 2 | 23 | 57° 14′ S, 84° 11′ E | 82 | *4* |
| 3 | 23 | " " | 88 | — |
| 4 | 25 | 57° 56′ S, 84° 27′ E | 86 | — |
| 5 | 30 | 57° 00′ S, 83° 24′ E | 80 | *2* |
| 6 | Nov. 3 | 58° 08′ S, 90° 59′ E | 88 | 22 |
| 7 | 4 | 58° 10′ S, 92° 40′ E | 91 | — |
| 8 | 6 | 58° 54′ S, 94° 03′ E | 85 | *8* |
| 9 | 6 | " " | 87 | *16* |
| 10 | 8 | 58° 23′ S, 96° 07′ E | 79 | *2* |
| 11 | 8 | " " | 88 | 9 |
| 12 | 8 | " " | 91 | *11* |
| 13 | 11 | 58° 25′ S, 101° 02′ E | 88 | *8* |
| 14 | 13 | 58° 07′ S, 102° 52′ E | 87 | *15* |
| 15 | 14 | 58° 06′ S, 103° 32′ E | 87 | *15* |
| 16 | 15 | 58° 13′ S, 103° 53′ E | 83 | — |
| 17 | 15 | " " | 83 | 1 |
| 18 | 18 | 59° 03′ S, 97° 38′ E | 89 | *16* |
| 19 | 19 | 58° 55′ S, 97° 38′ E | 90 | *21* |
| 20 | 20 | 58° 29′ S, 94° 47′ E | 88 | *12* |
| 21 | 21 | 58° 46′ S, 97° 58′ E | 85 | *14* |
| 22 | 23 | 58° 59′ S, 98° 29′ E | 84 | *2* |
| 23 | 24 | 59° 45′ S, 97° 24′ E | 80 | 0 |
| 24 | 24 | " " | 88 | 17 |
| 25 | 25 | 60° 05′ S, 96° 20′ E | 92 | *12* |
| 26 | 27 | 59° 54′ S, 96° 23′ E | 86 | *13* |
| 27 | 28 | 59° 47′ S, 96° 50′ E | 89 | *23* |
| 28 | 30 | 59° 46′ S, 97° 01′ E | 94 | *13* |
| 29 | Dec. 4 | 60° 21′ S, 96° 57′ E | 88 | *8* |
| 30 | 7 | 60° 43′ S, 97° 11′ E | 85 | 17 |
| 31 | 8 | 60° 53′ S, 96° 43′ E | 85 | *6* |
| 32 | 9 | 61° 13′ S, 96° 26′ E | 85 | *12* |
| 33 | 12 | 60° 57′ S, 96° 26′ E | 83 | 5 |
| 34 | 14 | 60° 41′ S, 96° 32′ E | 81 | — |
| 35 | 15 | 60° 28′ S, 96° 38′ E | 85 | 16 |
| 36 | 16 | 60° 39′ S, 96° 42′ E | 87 | *8* |
| 37 | 17 | 60° 30′ S, 97° 36′ E | 86 | *7* |
| 38 | 18 | 60° 55′ S, 97° 32′ E | 83 | *3* |
| 39 | 19 | 61° 20′ S, 96° 55′ E | 89 | *4* |
| 40 | 20 | 61° 16′ S, 97° 08′ E | 85 | 2 |
| 41 | 21 | 61° 14′ S, 97° 14′ E | 88 | 6 |
| 42 | 22 | 61° 27′ S, 97° 05′ E | 93 | *9* |
| 43 | 23 | 61° 32′ S, 97° 12′ E | 87 | *15* |
| 44 | 27 | 61° 52′ S, 96° 01′ E | 89 | 21 |
| 45 | 30 | 62° 33′ S, 96° 43′ E | 88 | *11* |
| | 1935 | | | |
| 46 | Jan. 2 | 62° 43′ S, 96° 13′ E | 86 | 26 |
| 47 | 4 | 62° 01′ S, 98° 31′ E | 86 | *12* |
| 48 | 5 | 62° 24′ S, 98° 30′ E | 80 | *15* |
| 49 | 5 | " " | 88 | 9 |
| 50 | 6 | 62° 33′ S, 98° 12′ E | 86 | 6 |
| 51 | 9 | 63° 58′ S, 110° 15′ E | 85 | 3 |
| | 1935 | | | |
| 52 | Jan. 10 | 64° 33′ S, 114° 23′ E | 85 | 17 |
| 53 | 11 | 64° 30′ S, 114° 00′ E | 86 | 9 |
| 54 | 12 | 64° 26′ S, 113° 17′ E | 85 | 17 |
| 55 | 18 | 64° 19′ S, 78° 45′ E | 87 | — |
| 56 | 19 | 64° 36′ S, 78° 07′ E | 93 | — |
| 57 | 19 | " " | 93 | *22* |
| 58 | 20 | 64° 21′ S, 77° 24′ E | 91 | *11* |
| 59 | 20 | " " | 85 | 19 |
| 60 | 22 | 64° 11′ S, 78° 44′ E | 86 | — |
| 61 | 22 | " " | 85 | *2* |
| 62 | 23 | 63° 44′ S, 81° 45′ E | 91 | 11 |
| 63 | 31 | 63° 23′ S, 79° 16′ E | 88 | *13* |
| 64 | 31 | " " | 80 | 1 |
| 65 | Feb. 1 | 64° 06′ S, 79° 19′ E | 91 | 8 |
| 66 | 2 | 63° 37′ S, 78° 23′ E | 88 | *15* |
| 67 | 4 | 62° 24′ S, 81° 26′ E | 87 | — |
| 68 | 4 | " " | 87 | 9 |
| 69 | 5 | 62° 18′ S, 81° 42′ E | 90 | *10* |
| 70 | 6 | 62° 13′ S, 83° 00′ E | 80 | 0 |
| 71 | 7 | 62° 02′ S, 82° 56′ E | 86 | 11 |
| 72 | 8 | " 83° 01′ E | 95 | 24 |
| 73 | 9 | " 82° 57′ E | 87 | *18* |
| 74 | 10 | 61° 41′ S, 83° 30′ E | 89 | 8 |
| 75 | 16 | 62° 57′ S, 83° 04′ E | 78 | 0 |
| 76 | 16 | " " | 83 | 10 |
| 77 | 17 | 62° 20′ S, 82° 34′ E | 91 | 9 |
| 78 | 18 | 62° 29′ S, 82° 05′ E | 90 | 9 |
| 79 | 19 | 63° 00′ S, 82° 50′ E | 93 | 10 |
| 80 | 19 | " " | 91 | 16 |
| 81 | 20 | 63° 12′ S, 83° 24′ E | 96 | 28 |
| 82 | 23 | 63° 10′ S, 85° 40′ E | 90 | 2 |
| 83 | 28 | 64° 10′ S, 91° 12′ E | 84 | *6* |
| 84 | Mar. 2 | 65° 09′ S, 83° 40′ E | 89 | *4* |
| 85 | 3 | 65° 19′ S, 82° 18′ E | 94 | 20 |
| 86 | 3 | " " | 89 | 6 |
| 87 | 3 | " " | 88 | 4 |
| 88 | 4 | 65° 16′ S, 81° 12′ E | 95 | 19 |
| 89 | 8 | 66° 07′ S, 72° 10′ E | 82 | — |
| 90 | 8 | " " | 82 | 3 |
| 91 | 12 | 66° 19′ S, 71° 50′ E | 88 | 22 |
| 92 | 12 | " " | 93 | — |
| 93 | 15 | " 71° 07′ E | 92 | 16 |
| 94 | 15 | " " | 86 | *7* |
| 95 | 17 | 66° 10′ S, 70° 00′ E | 86 | 5 |
| 96 | 26 | 65° 31′ S, 27° 51′ E | 80 | 0 |
| 97 | 27 | 65° 37′ S, 27° 02′ E | 90 | 2 |
| 98 | 28 | 65° 42′ S, 26° 45′ E | 91 | *3* |
| 99 | 30 | 65° 36′ S, 27° 58′ E | 83 | — |
| 100 | Apr. 1 | 65° 25′ S, 28° 03′ E | 78 | 0 |
| 100*a* | 3 | 65° 29′ S, 28° 55′ E | 90 | *10* |
| 100*b* | 4 | 65° 36′ S, 27° 54′ E | 97 | *12* |

## *Fl.F. 'Southern Empress'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| | 1934 | | | | | 1934 | | | |
| 101 | Oct. 17 | 56° 36′ S, 80° 30′ E | 82 | *7* | 154 | Dec. 28 | 61° 52′ S, 95° 38′ E | 83 | *6* |
| 102 | 18 | 56° 48′ S, 80° 57′ E | 79 | *1* | 155 | 30 | 62° 14′ S, 95° 19′ E | 87 | 18 |
| 103 | 18 | ,, ,, | 88 | *6* | 156 | 31 | 62° 35′ S, 94° 45′ E | 90 | 14 |
| 104 | 18 | ,, ,, | 78 | *1* | | 1935 | | | |
| 105 | 19 | 56° 42′ S, 81° 40′ E | 87 | *12* | 157 | Jan. 2 | 61° 49′ S, 97° 43′ E | 90 | *8* |
| 106 | 20 | 57° 00′ S, 81° 35′ E | 86 | 8 | 158 | 9 | 64° 12′ S, 115° 56′ E | 83 | *10* |
| 107 | 20 | ,, ,, | 90 | *23* | 159 | 9 | 64° 12′ S, 115° 56′ E | 85 | *24* |
| 108 | 21 | 57° 04′ S, 81° 51′ E | 85 | 3 | 160 | 10 | 64° 15′ S, 116° 00′ E | 88 | 6 |
| 109 | 22 | 56° 39′ S, 83° 35′ E | 86 | 17 | 161 | 10 | ,, ,, | 85 | 7 |
| 110 | 23 | 57° 37′ S, 86° 20′ E | 86 | *11* | 162 | 11 | 64° 10′ S, 115° 36′ E | 82 | *11* |
| 111 | 23 | ,, ,, | 84 | *11* | 163 | 11 | ,, ,, | 87 | 9 |
| 112 | 24 | 58° 13′ S, 86° 55′ E | 87 | 18 | 164 | 18 | ,, 85° 12′ E | 87 | *4* |
| 113 | 25 | 58° 59′ S, 88° 06′ E | 88 | *22* | 165 | 19 | 64° 22′ S, 84° 31′ E | 90 | 6 |
| 114 | 27 | 58° 35′ S, 90° 22′ E | 92 | *9* | 166 | 20 | 64° 30′ S, 84° 17′ E | 90 | 11 |
| 115 | 29 | 58° 29′ S, 93° 00′ E | 87 | *12* | 167 | 20 | ,, ,, | 90 | 23 |
| 116 | 31 | 58° 37′ S, 93° 25′ E | 91 | *5* | 168 | 21 | 64° 10′ S, 83° 30′ E | 80 | *3* |
| 117 | 31 | ,, ,, | 85 | *24* | 169 | 22 | 63° 46′ S, 84° 04′ E | 80 | *3* |
| 118 | Nov. 1 | 58° 30′ S, 93° 35′ E | 90 | *14* | 170 | 22 | ,, ,, | 80 | *11* |
| 119 | 3 | 58° 50′ S, 96° 46′ E | 86 | *13* | 171 | Feb. 2 | 64° 18′ S, 84° 00′ E | 83 | 7 |
| 120 | 4 | 58° 44′ S, 97° 08′ E | 98 | *6* | 172 | 2 | ,, ,, | 90 | *14* |
| 121 | 6 | 58° 35′ S, 98° 20′ E | 89 | *18* | 173 | 3 | 63° 56′ S, 83° 23′ E | 85 | 27 |
| 122 | 6 | ,, ,, | 95 | *20* | 174 | 4 | 63° 50′ S, 83° 18′ E | 88 | *16* |
| 123 | 8 | 58° 10′ S, 99° 10′ E | 96 | *18* | 175 | 4 | ,, ,, | 86 | 4 |
| 124 | 12 | 58° 20′ S, 100° 47′ E | 83 | *7* | 176 | 5 | 63° 59′ S, 86° 56′ E | 86 | — |
| 125 | 13 | 58° 13′ S, 102° 53′ E | 87 | *16* | 177 | 6 | 63° 39′ S, 83° 47′ E | 80 | 0 |
| 126 | 14 | 57° 43′ S, 101° 29′ E | 94 | *25* | 178 | 7 | 63° 05′ S, 83° 28′ E | 80 | 2 |
| 127 | 15 | 58° 09′ S, 100° 38′ E | 90 | *15* | 179 | 8 | 63° 00′ S, 85° 15′ E | 86 | *8* |
| 128 | 17 | 59° 32′ S, 98° 45′ E | 88 | 23 | 180 | 10 | 62° 36′ S, 82° 31′ E | 82 | *4* |
| 129 | 20 | 59° 27′ S, 98° 07′ E | 86 | 13 | 181 | 14 | 62° 26′ S, 84° 21′ E | 86 | *11* |
| 130 | 21 | 60° 00′ S, 98° 25′ E | 90 | *12* | 182 | 17 | 62° 50′ S, 84° 37′ E | 88 | 10 |
| 131 | 22 | ,, 98° 37′ E | 90 | *15* | 183 | 18 | 62° 51′ S, 84° 47′ E | 85 | 23 |
| 132 | 23 | 60° 22′ S, 98° 26′ E | 87 | *14* | 184 | 19 | 63° 00′ S, 88° 12′ E | 90 | 17 |
| 133 | 23 | ,, ,, | 84 | 5 | 185 | 20 | 63° 12′ S, 85° 50′ E | 85 | *6* |
| 134 | 26 | 60° 20′ S, 98° 48′ E | 93 | 21 | 186 | 21 | 63° 13′ S, 86° 20′ E | 81 | 3 |
| 135 | 29 | 60° 03′ S, 98° 40′ E | 90 | 19 | 187 | 23 | 63° 26′ S, 89° 08′ E | 87 | 4 |
| 136 | 30 | 60° 06′ S, 99° 00′ E | 80 | *18* | 188 | 23 | ,, ,, | 96(?) | 16 |
| 137 | 30 | ,, ,, | 86 | **21** | 189 | 24 | 63° 37′ S, 92° 07′ E | 93 | *7* |
| 138 | Dec. 2 | 60° 42′ S, 99° 30′ E | 87 | 17 | 190 | 25 | 63° 40′ S, 91° 36′ E | 86 | 23 |
| 139 | 4 | 60° 35′ S, 99° 02′ E | 83 | *13* | 191 | 25 | ,, ,, | 90 | *7* |
| 140 | 5 | 60° 54′ S, 99° 33′ E | 87 | *9* | 192 | 26 | 63° 40′ S, 92° 88′ E | 86 | 8 |
| 141 | 5 | ,, ,, | 82 | *2* | 193 | 28 | 63° 26′ S, 92° 05′ E | 89 | 9 |
| 142 | 6 | 60° 52′ S, 99° 40′ E | 84 | *6* | 194 | Mar. 6 | 65° 14′ S, 89° 08′ E | 92 | 18 |
| 143 | 6 | ,, ,, | 90 | 6 | 195 | 7 | 65° 22′ S, 88° 23′ E | 85 | 2 |
| 144 | 12 | 62° 25′ S, 101° 42′ E | 79 | *5* | 196 | 8 | 65° 15′ S, 86° 40′ E | 92 | 10 |
| 145 | 13 | 60° 20′ S, 102° 15′ E | 88 | *20* | 197 | 16 | 65° 20′ S, 87° 30′ E | 95 | *19* |
| 146 | 15 | 60° 22′ S, 102° 05′ E | 92 | *14* | 198 | 16 | ,, ,, | 92 | 16 |
| 147 | 18 | 60° 00′ S, 99° 10′ E | 89 | *6* | 199 | 18 | ,, 88° 40′ E | 88 | 7 |
| 148 | 19 | ,, 98° 45′ E | 85 | *8* | 200 | 18 | ,, ,, | 83 | 9 |
| 149 | 20 | 60° 32′ S, 98° 30′ E | 89 | *18* | 200*a* | 18 | ,, ,, | 86 | *9* |
| 150 | 21 | 60° 32′ S, 98° 30′ E | 85 | 3 | 200*b* | 18 | ,, ,, | 86 | *19* |
| 151 | 23 | 61° 12′ S, 97° 04′ E | 84 | 1 | 200*c* | 20 | 65° 29′ S, 80° 30′ E | 84 | *9* |
| 152 | 26 | 61° 44′ S, 96° 47′ E | 83 | 20 | 200*d* | 28 | 65° 18′ S, 32° 40′ E | 90 | 4 |
| 153 | 28 | 61° 52′ S, 95° 38′ E | 90 | 6 | | | | | |

## *Fl.F. 'New Sevilla'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| 201 | 1934<br>Dec. 1 | 56° 08′ S, 9° 19′ W | 79 | 0 | 250 | 1935<br>Jan. 22 | 59° 47′ S, 4° 18′ W | 86 | *17* |
| 202 | 1 | ,, ,, | 82 | 0 | 251 | 23 | 60° 08′ S, 4° 29′ W | 84 | *5* |
| 203 | 11 | 56° 41′ S, 1° 29′ W | 90 | 15 | 252 | 24 | 59° 47′ S, 4° 03′ W | 83 | *4* |
| 204 | 12 | 56° 34′ S, 1° 07′ W | 85 | 9 | 253 | 25 | 59° 35′ S, 4° 15′ W | 88 | *21* |
| 205 | 12 | ,, ,, | 85 | 18 | 254 | 26 | 59° 34′ S, 3° 28′ W | 85 | *5* |
| 206 | 13 | ,, 2° 14′ W | 91 | 15 | 255 | 31 | 60° 03′ S, 1° 43′ W | 90 | *4* |
| 207 | 14 | 56° 50′ S, 5° 08′ W | 82 | *12* | 256 | Feb. 1 | 60° 09′ S, 1° 04′ W | 85 | 10 |
| 208 | 17 | 57° 03′ S, 4° 29′ W | 79 | 19 | 257 | 1 | ,, ,, | 94 | 13 |
| 209 | 19 | 57° 02′ S, 3° 57′ W | 83 | *24* | 258 | 8 | 67° 49′ S, 20° 07′ E | 92 | 17 |
| 210 | 19 | ,, ,, | 82 | *29* | 259 | 8 | ,, ,, | 80 | 14 |
| 211 | 20 | 56° 59′ S, ,, | 83 | 7 | 260 | 11 | 67° 30′ S, 21° 39′ E | 83 | 7 |
| 212 | 21 | ,, 4° 33′ W | 89 | 17 | 261 | 11 | ,, ,, | 85 | 27 |
| 213 | 22 | 56° 56′ S, 4° 23′ W | 85 | 26 | 262 | 12 | 67° 09′ S, 21° 30′ E | 89 | 24 |
| 214 | 25 | 56° 46′ S, 4° 37′ W | 83 | 23 | 263 | 16 | 61° 27′ S, 2° 05′ E | 87 | 19 |
| 215 | 27 | 59° 06′ S, 10° 19′ W | 92 | *8* | 264 | 16 | ,, ,, | 92 | 21 |
| 216 | 28 | 59° 18′ S, 11° 52′ W | 86 | *6* | 265 | 16 | ,, ,, | 83 | *12* |
| 217 | 29 | 57° 37′ S, 9° 19′ W | 86 | 15 | 266 | 17 | 60° 52′ S, 0° 55′ E | 82 | *4* |
| 218 | 30 | 57° 56′ S, 7° 59′ W | 92 | 8 | 267 | 17 | 60° 52′ S, 0° 55′ E | 78 | *5* |
| 219 | 30 | ,, ,, | 86 | 15 | 268 | 17 | ,, ,, | 86 | 5 |
| 220 | 31 | 58° 05′ S, 7° 44′ W | 83 | 3 | 269 | 18 | 60° 71′ S, 0° 37′ E | 83 | *25* |
| 221 | 31 | ,, ,, | 81 | *15* | 270 | 18 | ,, ,, | 82 | *6* |
| 222 | 1935<br>Jan. 1 | 57° 56′ S, 7° 23′ W | 90 | *6* | 271 | 18 | ,, ,, | 87 | 25 |
| 223 | 2 | 58° 10′ S, 7° 40′ W | 78 | 2 | 272 | 20 | 60° 21′ S, 0° 04′ W | 81 | *2* |
| 224 | 2 | ,, ,, | 91 | *10* | 273 | 21 | 60° 30′ S, 0° 26′ E | 88 | *18* |
| 225 | 2 | ,, ,, | 90 | 10 | 274 | 25 | 61° 20′ S, 1° 23′ W | 82 | *7* |
| 226 | 3 | 58° 38′ S, 7° 00′ W | 86 | *21* | 275 | 26 | ,, 2° 10′ W | 83 | *14* |
| 227 | 3 | ,, ,, | 81 | *6* | 276 | 27 | 61° 28′ S, 3° 17′ W | 78 | 9 |
| 228 | 3 | ,, ,, | 88 | *4* | 277 | 28 | 61° 23′ S, 4° 07′ W | 90 | *21* |
| 229 | 4 | 58° 44′ S, 7° 01′ W | 85 | *12* | 278 | 28 | ,, ,, | 80 | — |
| 230 | 4 | ,, ,, | 94 | *14* | 279 | Mar. 6 | 62° 12′ S, 12° 29′ W | 86 | *8* |
| 231 | 5 | 58° 34′ S, 7° 14′ W | 90 | *9* | 280 | 7 | 62° 14′ S, 13° 07′ W | 84 | *5* |
| 232 | 6 | 58° 22′ S, 7° 23′ W | 82 | — | 281 | 8 | 62° 31′ S, 14° 12′ W | 86 | *18* |
| 233 | 8 | 58° 12′ S, 7° 48′ W | 80 | 3 | 282 | 9 | 62° 37′ S, 15° 25′ W | 80 | — |
| 234 | 9 | 58° 07′ S, 6° 30′ W | 85 | 9 | 283 | 14 | 64° 37′ S, 28° 52′ W | 85 | *23* |
| 235 | 9 | ,, ,, | 89 | 21 | 284 | 19 | 63° 41′ S, 46° 25′ W | 86 | 13 |
| 236 | 9 | ,, ,, | 88 | 8 | 285 | 20 | 64° 03′ S, 48° 51′ W | 80 | 0 |
| 237 | 10 | 58° 15′ S, 6° 19′ W | 80 | 12 | 286 | 21 | 63° 26′ S, 51° 07′ W | 82 | 3 |
| 238 | 10 | 58° 15′ S, 6° 19′ W | 81 | *3* | 287 | 21 | ,, ,, | 82 | 2 |
| 239 | 12 | 58° 36′ S, 5° 30′ W | 82 | 7 | 288 | 22 | 63° 19′ S, 51° 12′ W | 87 | *25* |
| 240 | 13 | 58° 41′ S, 5° 35′ W | 86 | *19* | 289 | 22 | ,, ,, | 78 | 0 |
| 241 | 15 | 59° 14′ S, 5° 25′ W | 90 | *8* | 290 | 22 | ,, ,, | 80 | 0 |
| 242 | 17 | 59° 16′ S, 4° 04′ W | 81 | 7 | 291 | 24 | 63° 26′ S, 51° 20′ W | 80 | 9 |
| 243 | 17 | ,, ,, | 81 | 11 | 292 | 24 | ,, ,, | 83 | 20 |
| 244 | 17 | ,, ,, | 81 | 2 | 293 | 25 | 63° 11′ S, 51° 03′ W | 83 | *17* |
| 245 | 18 | 59° 11′ S, 3° 56′ W | 83 | 5 | 294 | 26 | 62° 54′ S, 51° 40′ W | 86 | 11 |
| 246 | 19 | 59° 00′ S, 3° 44′ W | 85 | *12* | 295 | 26 | ,, ,, | 78 | 7 |
| 247 | 19 | ,, ,, | 85 | *10* | 296 | 26 | ,, ,, | 88 | *19* |
| 248 | 19 | ,, ,, | 86 | *13* | 297 | 26 | ,, ,, | 89 | *17* |
| 249 | 20 | 59° 13′ S, 3° 46′ W | 89 | 7 | 298 | 28 | 62° 37′ S, 53° 42 W | 84 | 29 |

## *Fl.F. 'Salvestria'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| 301 | 1934<br>Dec. 1 | 54° 00′ S, 14° 00′ W | 83 | 4 | 340 | 1935<br>Jan. 14 | ,, ,, | 88 | *9* |
| 302 | 1 | ,, ,, | 85 | 22 | 341 | 16 | 61° 00′ S, 34° 00′ W | 84 | 3 |
| 303 | 1 | ,, ,, | 84 | *18* | 342 | 16 | ,, ,, | 90 | *8* |
| 304 | 2 | ,, ,, | 85 | *13* | 343 | 16 | ,, ,, | 88 | — |
| 305 | 2 | ,, ,, | 86 | *10* | 344 | 17 | ,, ,, | 84 | 3 |
| 306 | 3 | 57° 00′ S, 14° 30′ W | 90 | 0 | 345 | 19 | ,, ,, | 85 | 4 |
| 307 | 3 | ,, ,, | 88 | 16 | 346 | 19 | ,, ,, | 80 | *1* |
| 308 | 3 | ,, ,, | 88 | *11* | 347 | 19 | ,, ,, | 87 | *1* |
| 309 | 10 | 58° 00′ S, 22° 00′ W | 84 | 11 | 348 | 21 | 62° 00′ S, 33° 30′ W | 84 | — |
| 310 | 10 | ,, ,, | 89 | *12* | 349 | 22 | ,, ,, | 89 | *7* |
| 311 | 10 | ,, ,, | 80 | 5 | 350 | 25 | ,, ,, | 84 | — |
| 312 | 10 | ,, ,, | 81 | 0 | 351 | 25 | ,, ,, | 85 | *1* |
| 313 | 18 | 60° 00′ S, 23° 00′ W | 91 | *5* | 352 | 26 | ,, ,, | 84 | *7* |
| 314 | 18 | ,, ,, | 89 | 16 | 353 | Feb. 2 | 62° 00′ S, 29° 30′ W | 83 | *7* |
| 315 | 18 | ,, ,, | 91 | 28 | 354 | 2 | ,, ,, | 82 | *10* |
| 316 | 18 | ,, ,, | 81 | 0 | 355 | 2 | ,, ,, | 85 | 2 |
| 317 | 20 | 59° 32′ S, 22° 24′ W | 94 | 3 | 356 | 3 | ,, 27° 00′ W | 90 | 12 |
| 318 | 20 | ,, ,, | 89 | *24* | 357 | 5 | ,, ,, | 93 | 8 |
| 319 | 20 | ,, ,, | 82 | 13 | 358 | 8 | ,, ,, | 84 | *16* |
| 320 | 20 | ,, ,, | 79 | 0 | 359 | 8 | ,, ,, | 83 | 4 |
| 321 | 21 | 50° 00′ S, 22° 00′ W | 87 | *22* | 360 | 9 | ,, ,, | 81 | *1* |
| 322 | 21 | ,, ,, | 81 | *12* | 361 | 24 | 66° 00′ S, 32° 00′ W | 80 | 0 |
| 323 | 21 | ,, ,, | 84 | 0 | 362 | 24 | ,, ,, | 83 | *5* |
| 324 | 21 | ,, ,, | 87 | 10 | 363 | 24 | ,, ,, | 81 | 0 |
| 325 | 23 | 59° 00′ S, 22° 00′ W | 85 | *4* | 364 | 26 | ,, ,, | 86 | 7 |
| 326 | 23 | ,, ,, | 88 | 8 | 365 | 26 | ,, ,, | 83 | 4 |
| 327 | 25 | 59° 00′ S, 23° 00′ W | 86 | 7 | 366 | 27 | ,, ,, | 91 | *11* |
| 328 | 25 | 59° 00′ S, 23° 00′ W | 79 | *12* | 367 | 27 | ,, ,, | 93 | *11* |
| 329 | 25 | ,, ,, | 89 | *12* | 368 | 28 | ,, ,, | 90 | *9* |
| 330 | 25 | ,, ,, | 89 | 5 | 369 | Mar. 1 | ,, 31° 00′ W | 87 | — |
| 331 | 25 | ,, ,, | 85 | 9 | 370 | 4 | ,, ,, | 85 | 6 |
| 332 | 29 | 60° 00′ S, 23° 30′ W | 87 | 5 | 371 | 5 | ,, ,, | 86 | *13* |
| 333 | 29 | ,, ,, | 85 | *7* | 372 | 9 | ,, ,, | 83 | — |
| 334 | 29 | ,, ,, | 88 | 16 | 373 | 10 | ,, ,, | 84 | 7 |
| 335 | 30 | ,, ,, | 86 | 9 | 374 | 10 | ,, ,, | 86 | 5 |
| 336 | 1935<br>Jan. 12 | 59° 00′ S, 24° 30′ W | 86 | 11 | 375 | 15 | ,, ,, | 80 | 0 |
| 337 | 13 | ,, ,, | 85 | *1* | 376 | 16 | ,, ,, | 87 | 8 |
| 338 | 13 | ,, ,, | 93 | *25* | 377 | 25 | ,, ,, | 85 | *8* |
| 339 | 14 | ,, ,, | 85 | *6* | 378 | 27 | ,, ,, | 84 | *4* |

## *Fl.F. 'Sir James Clark Ross'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| 401 | 1934<br>Dec. 4 | 59° 35′ S, 80° 03′ E | 78 | 0 | 427 | 1935<br>Jan. 10 | 63° 30′ S, 81° 56′ E | — | *9* |
| 402 | 5 | ,, ,, | 80 | 0 | 428 | 18 | 64° 52′ S, 60° 50′ E | 78 | *3* |
| 403 | 8 | 59° 16′ S, 84° 00′ E | 86 | — | 429 | 18 | 64° 52′ S, 60° 50′ E | 91 | 20 |
| 404 | 8 | ,, ,, | 91 | — | 430 | 19 | 64° 44′ S, 59° 00′ E | 84 | *11* |
| 405 | 8 | ,, ,, | 87 | *18* | 431 | 20 | 64° 42′ S, 55° 08′ E | 88 | 18 |
| 406 | 8 | ,, ,, | 91 | — | 432 | 20 | ,, ,, | 84 | 8 |
| 407 | 10 | 59° 32′ S, 85° 15′ E | 91 | — | 433 | 24 | 64° 03′ S, 48° 13′ E | 90 | 17 |
| 408 | 9 | 59° 55′ S, 84° 53′ E | 88 | — | 434 | 27 | 63° 42′ S, 47° 26′ E | 87 | *13* |
| 409 | 11 | 60° 00′ S, 85° 15′ E | — | — | 435 | 30 | 63° 40′ S, 47° 37′ E | 88 | 18 |
| 410 | 12 | 59° 42′ S, 85° 25′ E | 87 | 13 | 436 | 30 | ,, ,, | 89 | *19* |
| 411 | 13 | 60° 21′ S, 86° 00′ E | 91 | 16 | 437 | Feb. 2 | 64° 32′ S, 39° 37′ E | 93 | 16 |
| 412 | 14 | ,, ,, | 87 | 12 | 438 | 3 | 64° 11′ S, 36° 05′ E | 85 | 10 |
| 413 | 15 | ,, ,, | 90 | *13* | 439 | 4 | 64° 00′ S, 35° 05′ E | 86 | 3 |
| 414 | 16 | 60° 47′ S, 87° 40′ E | 88 | 8 | 440 | 8 | 64° 15′ S, 30° 07′ E | 83 | 1 |
| 415 | 17 | ,, ,, | 90 | *11* | 441 | 13 | 65° 00′ S, 31° 11′ E | 81 | *9* |
| 416 | 19 | 61° 45′ S, 91° 16′ E | 86 | 24 | 442 | 15 | 64° 50′ S, 33° 52′ E | 85 | *9* |
| 417 | 21 | ,, 91° 03′ E | 80 | *2* | 443 | 18 | 64° 40′ S, 34° 00′ E | 86 | 17 |
| 418 | 23 | 60° 35′ S, 94° 58′ E | — | 18 | 444 | Mar. 1 | ,, 32° 47′ E | 85 | 7 |
| 419 | 27 | 61° 12′ S, 92° 20′ E | 85 | *13* | 445 | 4 | 64° 10′ S, 35° 04′ E | 79 | 0 |
| 420 | 29 | 61° 20′ S, 87° 52′ E | 91 | *19* | 446 | 5 | 64° 50′ S, 36° 00′ E | 78 | 0 |
| 421 | 30 | 61° 24′ S, 86° 57′ E | 86 | *9* | 447 | 5 | ,, ,, | 86 | 2 |
| 422 | 1935<br>Jan. 7 | 63° 13′ S, 83° 12′ E | 87 | *21* | 448 | 6 | 65° 08′ S, 36° 30′ E | 93 | 14 |
| 423 | 8 | 63° 15′ S, 83° 00′ E | 86 | *8* | 449 | 7 | 64° 37′ S, 36° 58′ E | 88 | 8 |
| 424 | 8 | ,, ,, | 84 | *13* | 450 | 8 | 64° 30′ S, 34° 40′ E | 80 | 3 |
| 425 | 9 | 65° 19′ S, 82° 11′ E | — | 2 | 451 | 11 | 64° 37′ S, 34° 32′ E | 84 | *27* |
| 426 | 15 | 64° 45′ S, 66° 27′ E | 92 | *16* | 452 | 17 | 65° 59′ S, 30° 20′ E | 86 | *12* |

## *Fl.F. ‘Thorshammer’*

| Serial no. | Date of capture | Ship’s position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship’s position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| | 1934 | | | | | 1935 | | | |
| 501 | Nov. 5 | 28° 20′ S, 8° 30′ W | 75 | — | 545 | Jan. 12 | 61° 18′ S, 24° 52′ E | 82 | *10* |
| 502 | Dec. 2 | 56° 00′ S, 15° 00′ E | 83 | — | 546 | 12 | 61° 26′ S, 25° 49′ E | 81 | *16* |
| 503 | 4 | 56° 13′ S, 16° 00′ E | 82 | 3 | 547 | 12 | ,, ,, | 83 | *8* |
| 504 | 5 | 56° 28′ S, 17° 13′ E | 89 | 17 | 548 | 14 | 61° 41′ S, 26° 54′ E | 90 | *28* |
| 505 | 5 | 56° 05′ S, 19° 10′ E | 86 | — | 549 | 17 | 60° 55′ S, 29° 14′ E | 86 | *11* |
| 506 | 6 | 56° 00′ S, 19° 40′ E | 90 | 23 | 550 | 19 | 60° 58′ S, 29° 10′ E | 86 | *12* |
| 507 | 8 | 56° 08′ S, 20° 04′ E | 93 | 7 | 551 | 19 | ,, ,, | 81 | 2 |
| 508 | 14 | 56° 36′ S, 22° 21′ E | 90 | *5* | 552 | 19 | ,, ,, | 85 | *27* |
| 509 | 14 | 56° 40′ S, 23° 19′ E | 85 | *22* | 553 | 20 | 61° 04′ S, 29° 22′ E | 80 | *7* |
| 510 | 15 | ,, ,, | 82 | 17 | 554 | 20 | ,, ,, | 83 | 20 |
| 511 | 18 | 57° 15′ S, 24° 13′ E | 79 | 5 | 555 | 23 | 61° 25′ S, 27° 46′ E | 89 | 7 |
| 512 | 18 | 57° 32′ S, 24° 40′ E | 84 | *3* | 556 | 24 | 61° 25′ S, 27° 03′ E | 83 | 3 |
| 513 | 20 | 57° 30′ S, 26° 45′ E | 75 | 0 | 557 | 24 | ,, ,, | 82 | 9 |
| 514 | 21 | ,, ,, | 80 | *9* | 558 | 25 | ,, ,, | 89 | *20* |
| 515 | 21 | ,, ,, | 80 | *4* | 559 | 25 | ,, ,, | 80 | 1 |
| 516 | 21 | ,, ,, | 82 | 21 | 560 | 25 | 61° 27′ S, 26° 46′ E | 90 | *7* |
| 517 | 22 | 58° 09′ S, 27° 10′ E | 88 | — | 561 | 25 | ,, ,, | 80 | 0 |
| 518 | 23 | 58° 06′ S, 27° 30′ E | 82 | *4* | 562 | 26 | 61° 31′ S, 26° 29′ E | 85 | *8* |
| 519 | 24 | 58° 23′ S, 28° 01′ E | 85 | 4 | 563 | 28 | 61° 30′ S, 26° 08′ E | 86 | — |
| 520 | 25 | 58° 31′ S, 28° 36′ E | 79 | 0 | 564 | 29 | 61° 37′ S, 26° 10′ E | 86 | 23 |
| 521 | 25 | 58° 30′ S, ,, | 76 | 0 | 565 | 29 | ,, ,, | 87 | — |
| 522 | 26 | ,, ,, | 80 | 6 | 566 | 29 | ,, ,, | 80 | 1 |
| 523 | 27 | 59° 08′ S, 28° 25′ E | 81 | 3 | 567 | Feb. 2 | 62° 21′ S, 26° 00′ E | 87 | *19* |
| 524 | 27 | ,, ,, | 85 | *13* | 568 | 7 | 63° 10′ S, 26° 33′ E | 86 | *13* |
| 525 | 27 | ,, ,, | 84 | — | 569 | 7 | 63° 21′ S, 26° 29′ E | 85 | *18* |
| 526 | 27 | ,, ,, | 82 | *13* | 570 | 7 | ,, ,, | 84 | 9 |
| 527 | 27 | 59° 08′ S, 28° 25′ E | 87 | 6 | 571 | 8 | 63° 34′ S, 25° 15′ E | 81 | 9 |
| 528 | 28 | 58° 46′ S, 28° 27′ E | 82 | 4 | 572 | 8 | ,, ,, | 91 | 20 |
| 529 | 28 | 58° 48′ S, 28° 08′ E | 84 | *12* | 573 | 9 | ,, ,, | 85 | 18 |
| 530 | 28 | ,, ,, | 85 | *10* | 574 | 10 | 63° 56′ S, 24° 20′ E | 84 | 20 |
| 531 | 29 | ,, ,, | 90 | *18* | 575 | 12 | 64° 40′ S, 24° 39′ E | 84 | 24 |
| 532 | 29 | ,, ,, | 80 | *1* | 576 | 13 | 64° 39′ S, 25° 00′ E | 80 | *9* |
| 533 | 29 | ,, ,, | 83 | *8* | 577 | 17 | 65° 27′ S, 25° 10′ E | 86 | *33* |
| | 1935 | | | | 578 | 20 | 64° 07′ S, 18° 26′ E | 81 | *9* |
| 534 | Jan. 1 | 58° 45′ S, 26° 50′ E | 85 | 19 | 579 | 26 | 64° 52′ S, 19° 15′ E | 90 | *10* |
| 535 | 6 | 60° 54′ S, 25° 12′ E | 90 | 16 | 580 | 27 | 64° 37′ S, 18° 45′ E | 83 | 10 |
| 536 | 6 | ,, ,, | 88 | *12* | 581 | 27 | ,, ,, | 86 | 111 |
| 537 | 7 | ,, ,, | 86 | 9 | 582 | 28 | 64° 28′ S, 19° 04′ E | 87 | 3 |
| 538 | 9 | 61° 03′ S, 25° 00′ E | 84 | 13 | 583 | Mar. 8 | 65° 00′ S, 19° 46′ E | 93 | 11 |
| 539 | 9 | ,, ,, | 80 | 6 | 584 | 10 | 65° 21′ S, 19° 00′ E | 85 | 18 |
| 540 | 10 | ,, ,, | 89 | *19* | 585 | 10 | 65° 21′ S, 19° 00′ E | 85 | *11* |
| 541 | 10 | 61° 00′ S, ,, | 78 | 2 | 586 | 10 | ,, ,, | 84 | 5 |
| 542 | 11 | 61° 18′ S, 24° 52′ E | 87 | 13 | 587 | 14 | 67° 27′ S, 17° 27′ E | 78 | 8 |
| 543 | 11 | ,, ,, | 85 | *10* | 588 | 28 | 67° 00′ S, 19° 18′ E | 87 | 6 |
| 544 | 12 | ,, ,, | 82 | 5 | 589 | 29 | 66° 56′ S, 18° 40′ E | 79 | 12 |

## *Fl.F. ‘Kosmos II’*
### (No length data supplied)

| Serial no. | Date of capture | Ship's position | No. of corpora lutea | Serial no. | Date of capture | Ship's position | No. of corpora lutea |
|---|---|---|---|---|---|---|---|
| | 1934 | | | | 1934 | | |
| 601 | Dec. 1 | 60° 29′ S, 63° 45′ E | 16 | 640 | Dec. 16 | 62° 44′ S, 80° 34′ E | *14* |
| 602 | 1 | ,, ,, | 22 | 641 | 16 | ,, ,, | *17* |
| 603 | 1 | ,, ,, | 10 | 642 | 17 | 61° 38′ S, 79° 41′ E | *20* |
| 604 | 2 | 60° 17′ S, 65° 12′ E | 2 | 643 | 17 | ,, ,, | *9* |
| 605 | 2 | ,, ,, | *33* | 644 | 17 | ,, ,, | 22 |
| 606 | 2 | ,, ,, | 25 | 645 | 17 | ,, ,, | *12* |
| 607 | 3 | 60° 42′ S, 65° 28′ E | *15* | 646 | 18 | 61° 47′ S, 81° 56′ E | *3* |
| 608 | 3 | ,, ,, | *1* | 647 | 18 | ,, ,, | *10* |
| 609 | 3 | ,, ,, | *2* | 648 | 19 | 61° 50′ S, 81° 53′ E | *12* |
| 610 | 4 | 61° 03′ S, 68° 28′ E | *2* | 649 | 20 | 61° 49′ S, 83° 05′ E | *19* |
| 611 | 4 | ,, ,, | 16 | 650 | 20 | ,, ,, | *23* |
| 612 | 4 | ,, ,, | 0 | 651 | 21 | 61° 30′ S, 83° 04′ E | **32** |
| 613 | 5 | 61° 17′ S, 67° 32′ E | *11* | 652 | 22 | ,, 83° 09′ E | *15* |
| 614 | 5 | ,, ,, | *12* | 653 | 23 | 61° 22′ S, ,, | *2* |
| 615 | 5 | ,, ,, | 1 | 654 | 23 | ,, ,, | *9* |
| 616 | 6 | 61° 17′ S, 67° 22′ E | 0 | 655 | 23 | ,, ,, | *19* |
| 617 | 7 | 61° 52′ S, 67° 41′ E | *22* | 656 | 24 | 61° 41′ S, 84° 09′ E | *8* |
| 618 | 8 | 61° 46′ S, 67° 37′ E | 0 | 657 | 24 | ,, ,, | 22 |
| 619 | 8 | ,, ,, | 3 | 658 | 26 | 61° 49′ S, 85° 09′ E | *10* |
| 620 | 8 | ,, ,, | *19* | 659 | 27 | 61° 17′ S, 85° 07′ E | *3* |
| 621 | 9 | 61° 56′ S, 67° 27′ E | 8 | 660 | 28 | 61° 40′ S, 83° 33′ E | *23* |
| 622 | 10 | 61° 07′ S, 69° 12′ E | *6* | 661 | 29 | 63° 49′ S, 82° 54′ E | 25 |
| 623 | 10 | ,, ,, | *14* | 662 | 30 | 64° 11′ S, 81° 36′ E | *32* |
| 624 | 11 | 61° 43′ S, 70° 13′ E | *3* | 663 | 31 | 64° 24′ S, 81° 06′ E | — |
| 625 | 11 | ,, ,, | *11* | 664 | 31 | 64° 28′ S, ,, | — |
| 626 | 11 | ,, ,, | 18 | 665 | 31 | 64° 14′ S, 81° 08′ E | — |
| 627 | 12 | 62° 01′ S, 71° 22′ E | *13* | 666 | 31 | 64° 30′ S, 81° 38′ E | — |
| 628 | 12 | 62° 01′ S, 71° 22′ E | 2 | 667 | 31 | ,, 82° 08′ E | — |
| 629 | 12 | ,, ,, | *20* | 668 | 31 | 64° 23′ S, 81° 15′ E | — |
| 630 | 13 | 62° 03′ S, 71° 58′ E | *8* | 669 | 31 | 64° 27′ S, 81° 59′ E | — |
| 631 | 13 | ,, ,, | 13 | | 1935 | | |
| 632 | 13 | ,, ,, | 34 | 670 | Jan. 7 | 64° 40′ S, 80° 17′ E | 16 |
| 644 | 14 | 62° 16′ S, 72° 50′ E | 5 | 671 | 8 | 65° 02′ S, 78° 26′ E | *24* |
| 634 | 14 | ,, ,, | 32 | 672 | 9 | 65° 51′ S, 76° 41′ E | *11* |
| 635 | 14 | ,, ,, | 18 | 673 | 10 | 65° 27′ S, 78° 24′ E | *1* |
| 636 | 15 | 62° 11′ S, 76° 00′ E | 0 | 674 | 11 | 64° 09′ S, 83° 33′ E | *19* |
| 637 | 15 | ,, ,, | *20* | 675 | 12 | 64° 18′ S, 86° 00′ E | *16* |
| 638 | 15 | ,, ,, | 11 | 676 | 13 | 64° 01′ S, 87° 00′ E | *4* |
| 639 | 16 | 62° 44′ S, 80° 34′ E | 0 | 677 | 14 | ,, ,, | *7* |

## *Fl.F. ‘Skytteren’*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| | 1934 | | | | | 1935 | | | |
| 701 | Dec. 3 | 60° 00′ S, 57° 00′ E | 85 | *11* | 724 | Jan. 5 | 60° 00′ S, 44° 00′ E | 83 | *7* |
| 702 | 5 | ,, ,, | 78 | 1 | 725 | 5 | ,, ,, | 93 | *15* |
| 703 | 6 | ,, ,, | 78 | 0 | 726 | 7 | ,, ,, | 84 | *11* |
| 704 | 6 | ,, ,, | 81 | *4* | 727 | 10 | 61° 00′ S, 43° 00′ E | 86 | — |
| 705 | 6 | ,, ,, | 85 | *7* | 728 | 14 | ,, ,, | 85 | *10* |
| 706 | 12 | 60° 00′ S, 56° 00′ E | 85 | *1* | 729 | 14 | ,, ,, | 84 | 2 |
| 707 | 14 | 61° 00′ S, 54° 00′ E | 89 | *9* | 730 | 18 | 61° 00′ S, 43° 00′ E | 82 | *18* |
| 708 | 14 | ,, ,, | 80 | 13 | 731 | 24 | 62° 00′ S, 40° 00′ E | 87 | *8* |
| 709 | 14 | ,, ,, | 86 | *17* | 732 | 25 | ,, ,, | 82 | 1 |
| 710 | 14 | ,, ,, | 85 | 5 | 733 | 26 | ,, ,, | 86 | *10* |
| 711 | 15 | ,, 53° 00′ E | 89 | *24* | 734 | 29 | ,, ,, | 82 | *4* |
| 712 | 15 | ,, ,, | 85 | *18* | 735 | 30 | 62° 00′ S, 39° 00′ E | 81 | *14* |
| 713 | 16 | ,, ,, | 85 | 23 | 736 | 31 | ,, ,, | 86 | 12 |
| 714 | 18 | 61° 00′ S, 49° 00′ E | 94 | 16 | 737 | Feb. 3 | ,, ,, | 86 | 14 |
| 715 | 19 | ,, ,, | 80 | 2 | 738 | 8 | ,, ,, | 86 | *27* |
| 716 | 20 | ,, ,, | 78 | 0 | 739 | 11 | ,, 40° 00′ E | 84 | — |
| 717 | 20 | ,, ,, | 86 | 20 | 740 | 16 | 64° 00′ S, 39° 00′ E | 82 | — |
| 718 | 22 | ,, ,, | 78 | 2 | 741 | 24 | 65° 00′ S, 39° 00′ E | 88 | — |
| 719 | 22 | ,, ,, | 81 | 3 | 742 | 28 | ,, 47° 00′ E | 87 | *14* |
| 720 | 22 | ,, ,, | 87 | — | 743 | Mar. 1 | ,, ,, | 89 | **20** |
| 721 | 23 | ,, ,, | 82 | *11* | 744 | 2 | ,, ,, | 85 | — |
| 722 | 28 | 60° 00′ S, 46° 00′ E | 85 | *13* | | | | | |
| 723 | 30 | ,, 44° 00′ E | 81 | *12* | | | | | |

## *Fl.F. 'Sir James Clark Ross'*

(No dates available)

1935–6

| Serial no. | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|
| 101 | 56° 02′ S, 18° 25′ E | 83 | 17 | 151 | 60° 35′ S, 28° 00′ E | 87 | — |
| 102 | " " | 87 | 0 | 152 | 60° 36′ S, 27° 40′ E | 83 | *4* |
| 103 | 56° 35′ S, 19° 54′ E | 89 | *19* | 153 | 60° 56′ S, 27° 40′ E | 82 | *8* |
| 104 | " " | 89 | 12 | 154 | " " | 82 | 3 |
| 105 | 56° 38′ S, 18° 48′ E | 88 | *10* | 155 | " " | 80 | 9 |
| 106 | " " | 84 | 3 | 156 | 60° 47′ S, 27° 45′ E | 80 | 0 |
| 107 | " " | 86 | *12* | 157 | 60° 57′ S, 28° 23′ E | 79 | 0 |
| 108 | " " | 85 | *7* | 158 | " " | 81 | *1* |
| 109 | 56° 40′ S, 18° 30′ E | 86 | *4* | 159 | " " | 84 | *7* |
| 110 | " " | 80 | 9 | 160 | 61° 17′ S, 27° 54′ E | 79 | 11 |
| 111 | " " | 94 | *10* | 161 | " " | 89 | *26* |
| 112 | " " | 78 | 0 | 162 | 61° 25′ S, " | 84 | *5* |
| 113 | " " | 84 | *5* | 163 | 61° 23′ S, 28° 20′ E | 85 | *6* |
| 114 | 56° 59′ S, 17° 53′ E | 89 | *16* | 164 | 61° 23′ S, 28° 26′ E | 79 | *2* |
| 115 | " " | 87 | *18* | 165 | 62° 00′ S, 28° 26′ E | 88 | *12* |
| 116 | " " | 85 | *10* | 166 | 62° 14′ S, 28° 08′ E | 81 | *3* |
| 117 | " " | 78 | 0 | 167 | 62° 57′ S, 28° 40′ E | 81 | — |
| 118 | 56° 55′ S, 18° 00′ E | 83 | *13* | 168 | " 28° 41′ E | 85 | *11* |
| 119 | " " | 88 | *8* | 169 | 62° 47′ S, 28° 55′ E | 90 | *11* |
| 120 | " " | 90 | *20* | 170 | 62° 56′ S, 29° 15′ E | 89 | *17* |
| 121 | " " | 87 | *12* | 171 | 63° 30′ S, 30° 36′ E | 83 | 10 |
| 122 | 57° 00′ S, 18° 15′ E | 88 | 14 | 172 | 63° 41′ S, 31° 01′ E | 83 | — |
| 123 | " " | 91 | *21* | 173 | 63° 48′ S, 30° 20′ E | 86 | 5 |
| 124 | 57° 10′ S, " | 81 | *6* | 174 | 64° 03′ S, 30° 34′ E | 78 | 0 |
| 125 | " " | 87 | 5 | 175 | 64° 25′ S, 31° 25′ E | 82 | — |
| 126 | 57° 51′ S, 18° 18′ E | 88 | *6* | 176 | 64° 53′ S, 31° 28′ E | 86 | 0 |
| 127 | " " | 79 | 16 | 177 | " " | 78 | 0 |
| 128 | " " | 87 | 0 | 178 | 65° 00′ S, " | 78 | 0 |
| 129 | 57° 52′ S, 18° 03′ E | 88 | *10* | 179 | " " | 87 | 0 |
| 130 | 57° 52′ S, 18° 03′ E | 90 | *20* | 180 | 65° 03′ S, 31° 30′ E | 80 | 12 |
| 131 | " " | 84 | *4* | 181 | 64° 50′ S, 31° 10′ E | 78 | 8 |
| 132 | 57° 47′ S, 18° 25′ E | 83 | 11 | 182 | 65° 27′ S, 32° 00′ E | 84 | 5 |
| 133 | " " | 86 | *10* | 183 | 65° 25′ S, 32° 45′ E | 90 | *14* |
| 134 | " " | 87 | *22* | 184 | " " | 86 | *7* |
| 135 | 57° 15′ S, 18° 40′ E | 87 | 0 | 185 | 65° 27′ S, 32° 15′ E | 91 | *5* |
| 136 | " " | 81 | 13 | 186 | " " | 90 | 1 |
| 137 | 58° 54′ S, 19° 30′ E | 88 | *17* | 187 | 66° 14′ S, 29° 35′ E | 84 | 8 |
| 138 | 58° 34′ S, 19° 34′ E | 80 | 18 | 188 | 65° 42′ S, 32° 20′ E | 90 | 17 |
| 139 | 58° 18′ S, 19° 42′ E | 85 | *22* | 189 | 65° 09′ S, 33° 40′ E | 79 | *2* |
| 140 | 58° 15′ S, 19° 15′ E | 87 | *8* | 190 | 66° 40′ S, 31° 48′ E | 91 | 20 |
| 141 | " " | 91 | *20* | 191 | " " | 81 | *2* |
| 142 | 58° 33′ S, 19° 20′ E | 84 | 13 | 192 | 66° 44′ S, " | 89 | 9 |
| 143 | 58° 45′ S, 15° 16′ E | 86 | *11* | 193 | " " | 81 | 1 |
| 144 | 60° 04′ S, 18° 06′ E | 87 | 25 | 194 | " " | 78 | *2* |
| 145 | 60° 47′ S, 22° 39′ E | 84 | 4 | 195 | 66° 48′ S, 32° 18′ E | 86 | — |
| 146 | 60° 46′ S, 25° 55′ E | 82 | *8* | 196 | " " | 83 | *14* |
| 147 | 60° 27′ S, 27° 38′ E | 87 | *24* | 197 | 67° 03′ S, 29° 48′ E | 81 | 0 |
| 148 | 60° 35′ S, 28° 00′ E | 82 | *7* | 198 | 67° 01′ S, 31° 24′ E | 83 | 13 |
| 149 | " " | 81 | *4* | 199 | 67° 09′ S, 30° 30′ E | 81 | 9 |
| 150 | " " | 94 | 19 | 200 | 66° 47′ S, 25° 35′ E | 84 | 8 |

## Fl.F. '*New Sevilla*'

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| 401 | 1935<br>Dec. 1 | 55° 42′ S, 22° 16′ E | 82 | *28* | 443 | 1936<br>Jan. 5 | 58° 31′ S, 19° 22′ E | 87 | 5 |
| 402 | 2 | 55° 50′ S, 20° 07′ E | 85 | 6 | 444 | 8 | 58° 29′ S, 19° 57′ E | 80 | *1* |
| 403 | 2 | ” ” | 82 | *6* | 445 | 9 | 58° 33′ S, 19° 50′ E | 85 | *12* |
| 404 | 2 | ” ” | 83 | 6 | 446 | 9 | ” ” | 86 | 4 |
| 405 | 2 | ” ” | 81 | *3* | 447 | 11 | 58° 30′ S, 20° 15′ E | 86 | 10 |
| 406 | 2 | ” ” | 89 | 5 | 448 | 12 | 57° 57′ S, 20° 40′ E | 91 | *11* |
| 407 | 2 | ” ” | 80 | *2* | 449 | 12 | ” ” | 86 | *17* |
| 408 | 10 | 56° 57′ S, 17° 58′ E | 88 | *3* | 450 | 12 | ” ” | 91 | *23* |
| 409 | 12 | 56° 30′ S, 17° 20′ E | 86 | 5 | 451 | 13 | 55° 55′ S, 19° 51′ E | 88 | *7* |
| 410 | 13 | 56° 22′ S, 17° 10′ E | 78 | *1* | 452 | 13 | ” ” | 80 | 3 |
| 411 | 14 | 56° 10′ S, 16° 55′ E | 79 | 0 | 701 | 15 | 57° 34′ S, 21° 17′ E | 88 | *18* |
| 412 | 14 | ” ” | 78 | *1* | 702 | 15 | ” ” | 86 | — |
| 413 | 15 | 56° 13′ S, 16° 54′ E | 83 | 0 | 703 | 16 | 57° 40′ S, 21° 20′ E | 87 | 17 |
| 414 | 15 | ” ” | 85 | *10* | 704 | 16 | ” ” | 86 | 6 |
| 415 | 15 | ” ” | 80 | *1* | 705 | 17 | 57° 53′ S, 22° 00′ E | 86 | *10* |
| 416 | 15 | ” ” | 89 | *8* | 706 | 17 | ” ” | 84 | *15* |
| 417 | 16 | 56° 22′ S, 15° 20′ E | 80 | *1* | 707 | 17 | 57° 53′ S, 22° 00′ E | 90 | *24* |
| 418 | 17 | 56° 35′ S, 17° 00′ E | 84 | 6 | 708 | 17 | ” ” | 92 | *5* |
| 419 | 18 | 56° 34′ S, 16° 34′ E | 90 | *21* | 709 | 18 | 58° 80′ S, 21° 50′ E | 87 | *9* |
| 420 | 18 | ” ” | 88 | *10* | 710 | 19 | 51° 14′ S, 21° 44′ E | 88 | *5* |
| 421 | 19 | 56° 22′ S, 15° 46′ E | 88 | *21* | 711 | 20 | 59° 31′ S, 22° 33′ E | 81 | *11* |
| 422 | 19 | ” ” | 86 | *7* | 712 | 20 | ” ” | 83 | 3 |
| 423 | 21 | 56° 40′ S, 15° 33′ E | 87 | 14 | 713 | 22 | 59° 48′ S, 22° 48′ E | 85 | *4* |
| 424 | 22 | 56° 55′ S, 15° 15′ E | 84 | *5* | 714 | 22 | ” ” | 85 | 15 |
| 425 | 23 | 56° 50′ S, 18° 24′ E | 87 | *13* | 715 | 23 | 59° 54′ S, 22° 58′ E | 88 | *15* |
| 426 | 25 | 57° 00′ S, 18° 30′ E | 84 | — | 716 | 23 | ” ” | 89 | *9* |
| 427 | 26 | 57° 21′ S, 18° 55′ E | 83 | *8* | 717 | 23 | ” ” | 83 | 2 |
| 428 | 26 | ” ” | 83 | 6 | 718 | 23 | ” ” | 85 | *9* |
| 429 | 27 | 57° 27′ S, 18° 00′ E | 88 | *18* | 719 | 24 | 60° 00′ S, 23° 06′ E | 87 | *19* |
| 430 | 28 | 58° 13′ S, 20° 80′ E | 86 | *14* | 720 | 26 | 60° 33′ S, 22° 47′ E | 83 | *11* |
| 431 | 29 | 58° 34′ S, 20° 21′ E | 91 | *18* | 721 | Feb. 4 | 28° 41′ S, 25° 43′ E | 84 | 7 |
| 432 | 30 | 58° 47′ S, 19° 55′ E | 88 | *18* | 722 | 6 | 58° 14′ S, 27° 57′ E | 87 | *10* |
| 433 | 31 | 58° 46′ S, 19° 42′ E | 84 | *18* | 723 | 7 | 58° 58′ S, 28° 14′ E | 87 | 7 |
| 434 | 1936<br>Jan. 1 | 58° 37′ S, 19° 51′ E | 82 | *3* | 724 | 7 | ” ” | 86 | *11* |
| 435 | 2 | 58° 40′ S, 19° 41′ E | 84 | 0 | 725 | 7 | ” ” | 86 | *5* |
| 436 | 2 | ” ” | 83 | 4 | 726 | 8 | 59° 07′ S, 25° 06′ E | 91 | — |
| 437 | 2 | ” ” | 78 | 2 | 727 | 8 | ” ” | 86 | — |
| 438 | 3 | 58° 40′ S, 19° 26′ E | 83 | *7* | 728 | 8 | ” ” | 92 | *14* |
| 439 | 4 | 58° 35′ S, 19° 30′ E | 85 | *5* | 729 | 8 | ” ” | 83 | *1* |
| 440 | 4 | ” ” | 87 | *20* | 730 | 9 | 59° 23′ S, 28° 14′ E | 85 | 24 |
| 441 | 5 | 58° 31′ S, 19° 22′ E | 86 | *10* | 731 | 11 | 59° 44′ S, 29° 46′ E | 86 | 2 |
| 442 | 5 | ” ” | 84 | *9* | 732 | 12 | 58° 50′ S, 29° 55′ E | 83 | 1 |

## *Fl.F. ‘Thorshammer’*

| Serial no. | Date of capture | Ship’s position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship’s position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| 501 | 1935<br>Dec. 3 | 55° 48′ S, 11° 48′ E | 78 | 9 | 542 | 1936<br>Jan. 4 | 59° 51′ S, 9° 02′ E | 83 | 2 |
| 502 | 4 | 55° 48′ S, 11° 52′ E | 80 | *1* | 543 | 4 | ” ” | 79 | *5* |
| 503 | 4 | ” ” | 86 | *21* | 544 | 5 | 59° 56′ S, 8° 56′ E | 85 | 10 |
| 504 | 4 | ” ” | 87 | *9* | 545 | 6 | 60° 12′ S, 8° 55′ E | 80 | *5* |
| 505 | 5 | 55° 46′ S, 12° 06′ E | 78 | *4* | 546 | 7 | 60° 34′ S, 8° 53′ E | 88 | 6 |
| 506 | 6 | 55° 42′ S, 12° 30′ E | 69 | 2 | 547 | 8 | 59° 53′ S, 8° 14′ E | 84 | 5 |
| 507 | 11 | 57° 33′ S, 13° 19′ E | 80 | *5* | 548 | 8 | ” ” | 84 | *6* |
| 508 | 12 | 57° 46′ S, 13° 08′ E | 83 | *27* | 549 | 9 | 59° 38′ S, 7° 43′ E | 90 | 14 |
| 509 | 13 | 57° 55′ S, 13° 33′ E | 78 | — | 550 | 10 | 58° 29′ S, 7° 35′ E | 83 | *13* |
| 510 | 14 | 57° 51′ S, 13° 56′ E | 85 | — | 551 | 11 | 58° 20′ S, 7° 50′ E | 83 | *27* |
| 511 | 14 | ” ” | 84 | 9 | 552 | 16 | 58° 36′ S, 10° 38′ E | 88 | 11 |
| 512 | 14 | ” ” | 80 | — | 553 | 16 | ” ” | 84 | 9 |
| 513 | 14 | ” ” | 81 | 6 | 554 | 17 | 58° 28′ S, 12° 22′ E | 80 | 3 |
| 514 | 14 | ” ” | 86 | *24* | 555 | 17 | ” ” | 82 | *7* |
| 515 | 15 | 58° 01′ S, 14° 02′ E | 74 | 24 | 556 | 18 | 58° 36′ S, 13° 00′ E | 79 | 1 |
| 516 | 16 | 57° 46′ S, 13° 21′ E | 87 | 10 | 557 | 20 | 58° 44′ S, 14° 05′ E | 83 | 27 |
| 517 | 17 | 57° 18′ S, 12° 43′ E | 80 | *1* | 558 | 25 | 59° 42′ S, 14° 39′ E | 84 | 17 |
| 518 | 17 | ” ” | 88 | *26* | 559 | 29 | 60° 16′ S, 17° 33′ E | 90 | 17 |
| 519 | 17 | ” ” | 80 | 2 | 560 | 30 | 60° 29′ S, 18° 36′ E | 85 | *17* |
| 520 | 18 | 56° 48′ S, 12° 00′ E | 87 | 10 | 561 | Feb. 7 | 63° 30′ S, 19° 55′ E | 77 | 3 |
| 521 | 18 | ” ” | 83 | 11 | 562 | 10 | 61° 53′ S, 21° 45′ E | 84 | *8* |
| 522 | 18 | ” ” | 89 | *16* | 563 | 15 | 67° 29′ S, 26° 29′ E | 85 | 19 |
| 523 | 19 | 56° 21′ S, 11° 48′ E | 86 | *23* | 564 | 18 | 67° 16′ S, 24° 37′ E | 82 | *9* |
| 524 | 19 | ” ” | 84 | 7 | 565 | 22 | 68° 34′ S, 17° 19′ E | 84 | 9 |
| 525 | 20 | 56° 12′ S, 12° 18′ E | 91 | *3* | 566 | 22 | ” ” | 84 | 4 |
| 526 | 21 | 57° 00′ S, 13° 07′ E | 80 | 9 | 567 | 22 | ” ” | 82 | 1 |
| 527 | 22 | 58° 14′ S, 12° 47′ E | 90 | *12* | 568 | 22 | ” ” | 84 | *9* |
| 528 | 23 | 58° 47′ S, 13° 23′ E | 89 | *9* | 569 | 22 | ” ” | 86 | 10 |
| 529 | 23 | 58° 47′ S, 13° 23′ E | 84 | *8* | 570 | 23 | 68° 27′ S, 17° 15′ E | 86 | 10 |
| 530 | 23 | ” ” | 86 | 17 | 571 | 23 | ” ” | 84 | *8* |
| 531 | 24 | 58° 44′ S, 13° 19′ E | 84 | *5* | 572 | 24 | 68° 26′ S, 17° 42′ E | 88 | *13* |
| 532 | 26 | 58° 34′ S, 14° 35′ E | 94 | 3 | 573 | 25 | 67° 51′ S, 16° 36′ E | 89 | 10 |
| 533 | 27 | 58° 57′ S, 14° 17′ E | 85 | — | 574 | 26 | 68° 11′ S, 14° 15′ E | 86 | 12 |
| 534 | 27 | ” ” | 90 | 9 | 575 | 26 | ” ” | 86 | *21* |
| 535 | 28 | 59° 48′ S, 14° 16′ E | 89 | *12* | 576 | Mar. 3 | 67° 00′ S, 7° 30′ E | 81 | 9 |
| 536 | 29 | 60° 09′ S, 14° 15′ E | 87 | *4* | 577 | 3 | ” ” | 88 | *7* |
| 537 | 30 | ” ” | 87 | 9 | 578 | 3 | ” ” | 72 | — |
| 538 | 1936<br>Jan. 3 | 59° 39′ S, 10° 24′ E | 83 | 3 | 579 | 4 | 67° 37′ S, 7° 02′ E | 85 | 20 |
| 539 | 3 | ” ” | 88 | — | 580 | 4 | ” ” | 85 | 11 |
| 540 | 4 | 59° 51′ S, 9° 02′ E | 87 | 19 | 581 | 5 | 67° 38′ S, 7° 41′ E | 89 | *12* |
| 541 | 4 | ” ” | 84 | *4* | 582 | 5 | ” ” | 88 | 16 |

### *Fl.F. ‘Southern Princess’*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| | 1935 | | | | | 1936 | | | |
| 601 | Dec. 1 | 58° 54′ S, 30° 27′ E | 78 | 0 | 633 | Jan. 7 | 63° 34′ S, 42° 54′ E | 86 | 3 |
| 602 | 2 | 58° 49′ S, 30° 47′ E | 84 | *4* | 634 | 7 | ,, ,, | 80 | 0 |
| 603 | 3 | 59° 07′ S, 30° 30′ E | 84 | *11* | 635 | 10 | 62° 53′ S, 41° 24′ E | 87 | 18 |
| 604 | 4 | 58° 58′ S, 30° 02′ E | 91 | *19* | 636 | 11 | 62° 42′ S, 41° 05′ E | 82 | 0 |
| 605 | 5 | 58° 46′ S, 29° 51′ E | 86 | *5* | 637 | 12 | 63° 05′ S, 42° 30′ E | 84 | 24 |
| 606 | 6 | 58° 31′ S, 29° 50′ E | 91 | 12 | 638 | 14 | 63° 18′ S, 42° 41′ E | 82 | — |
| 607 | 7 | 58° 19′ S, 30° 22′ E | 86 | *10* | 640 | 17 | ,, 38° 23′ E | 82 | 0 |
| 608 | 8 | 58° 15′ S, 30° 57′ E | 86 | *11* | 2211 | 17 | ,, ,, | 80 | 6 |
| 609 | 9 | 58° 06′ S, 30° 48′ E | 89 | *18* | 641 | 17 | ,, ,, | 85 | 5 |
| 610 | 11 | 59° 33′ S, 31° 27′ E | 86 | *7* | 642 | 19 | 63° 01′ S, 38° 04′ E | 79 | — |
| 611 | 12 | 59° 14′ S, 30° 30′ E | 82 | 21 | 643 | 20 | 62° 53′ S, 37° 42′ E | 79 | *1* |
| 612 | 13 | 58° 31′ S, 29° 30′ E | 82 | 17 | 644 | 24 | 62° 42′ S, 36° 48′ E | 80 | 0 |
| 613 | 13 | ,, ,, | 92 | *12* | 645 | 25 | 62° 08′ S, 27° 11′ E | 82 | 3 |
| 614 | 14 | 59° 01′ S, 29° 59′ E | 78 | 0 | 646 | 30 | 62° 57′ S, 36° 02′ E | 84 | — |
| 615 | 18 | 59° 17′ S, 31° 49′ E | 82 | 0 | 647 | 30 | ,, ,, | 78 | 0 |
| 616 | 19 | 59° 57′ S, 31° 56′ E | 84 | *14* | 2201 | 31 | ,, 35° 23′ E | 85 | 20 |
| 617 | 19 | ,, ,, | 85 | *2* | 2202 | 31 | ,, ,, | 79 | 0 |
| 618 | 19 | ,, ,, | 82 | *5* | 2203 | 31 | ,, ,, | 84 | 3 |
| 619 | 20 | 60° 08′ S, 31° 47′ E | 87 | 10 | 2204 | Feb. 2 | 62° 52′ S, 36° 04′ E | 82 | 5 |
| 620 | 20 | ,, ,, | 91 | 4 | 2205 | 7 | 63° 28′ S, 32° 56′ E | 80 | 0 |
| 621 | 21 | 60° 16′ S, 31° 54′ E | 82 | 11 | 2206 | 8 | 63° 59′ S, 33° 19′ E | 86 | 15 |
| 622 | 22 | 60° 21′ S, 31° 54′ E | 86 | 2 | 654 | 16 | 65° 53′ S, 32° 23′ E | 90 | *19* |
| | 1936 | | | | 655 | 17 | 65° 42′ S, 32° 19′ E | 88 | 15 |
| 627 | Jan. 2 | 65° 17′ S, 39° 35′ E | 82 | *1* | 656 | 17 | ,, ,, | 84 | 14 |
| 628 | 4 | 63° 27′ S, 41° 70′ E | 79 | 0 | 657 | 19 | 65° 22′ S, 33° 15′ E | 81 | 2 |
| 629 | 5 | 63° 31′ S, 41° 03′ E | 79 | 4 | 658 | Mar. 3 | 66° 51′ S, 35° 29′ E | 86 | 21 |
| 630 | 6 | 63° 28′ S, 42° 14′ E | 78 | 2 | 659 | 5 | 67° 15′ S, 36° 57′ E | 89 | 10 |
| 631 | 6 | ,, ,, | 80 | 0 | 660 | 6 | 67° 30′ S, 37° 13′ E | 79 | — |
| 632 | 7 | 63° 34′ S, 42° 54′ E | 82 | 9 | 661 | 7 | 67° 20′ S, 38° 25′ E | 86 | 6 |

## *Fl.F. 'Southern Empress'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|
| | 1935 | | | |
| 901 | Dec. 2 | 58° 38′ S, 74° 34′ E | 82 | *2* |
| 902 | 2 | ,, ,, | 86 | *9* |
| 903 | 2 | ,, ,, | 87 | 6 |
| 904 | 3 | 58° 17′ S, 76° 41′ E | 83 | 0 |
| 905 | 4 | 58° 01′ S, 78° 53′ E | 84 | *13* |
| 906 | 5 | 58° 11′ S, 81° 34′ E | 85 | 6 |
| 907 | 6 | 58° 06′ S, 83° 36′ E | 92 | *16* |
| 908 | 7 | 58° 17′ S, 84° 15′ E | 82 | 0 |
| 909 | 10 | 59° 20′ S, 87° 15′ E | 89 | 8 |
| 910 | 10 | ,, ,, | 86 | *10* |
| 911 | 11 | 59° 17′ S, 87° 34′ E | 79 | *19* |
| 912 | 14 | 59° 42′ S, 87° 25′ E | 90 | *10* |
| 913 | 14 | ,, ,, | 83 | *15* |
| 914 | 15 | 60° 00′ S, 88° 09′ E | 87 | 6 |
| 915 | 16 | 60° 23′ S, 87° 56′ E | 88 | *5* |
| 916 | 17 | 60° 59′ S, 88° 04′ E | 92 | 10 |
| 917 | 17 | ,, ,, | 90 | 16 |
| 918 | 19 | 60° 39′ S, 87° 00′ E | 85 | 15 |
| 919 | 19 | ,, ,, | 87 | *25* |
| 920 | 20 | 60° 05′ S, 87° 20′ E | 90 | *9* |
| 921 | 24 | 60° 44′ S, 87° 36′ E | 89 | *18* |
| 922 | 24 | ,, ,, | 87 | 0 |
| 923 | 25 | 60° 58′ S, 88° 18′ E | 80 | *1* |
| 924 | 26 | 60° 33′ S, 89° 09′ E | 87 | *1* |
| 925 | 27 | 60° 38′ S, 89° 15′ E | 86 | *13* |
| 926 | 28 | 60° 20′ S, 87° 39′ E | 83 | *8* |
| 927 | 28 | ,, ,, | 85 | *13* |
| 928 | 29 | 60° 27′ S, 87° 35′ E | 87 | *12* |
| 929 | 29 | ,, ,, | 83 | *5* |
| | 1936 | | | |
| 930 | Jan. 2 | 60° 00′ S, 87° 40′ E | 85 | *10* |
| 931 | 5 | 60° 08′ S, 88° 24′ E | 85 | 9 |
| 932 | 5 | ,, ,, | 84 | 16 |
| 933 | 6 | ,, 88° 20′ E | 81 | 0 |
| 934 | 6 | ,, ,, | 93 | 25 |
| 935 | 6 | ,, ,, | 80 | 0 |
| 936 | 9 | 61° 07′ S, 87° 31′ E | 82 | *2* |
| 937 | 9 | ,, ,, | 86 | *7* |
| 938 | 11 | 61° 15′ S, 87° 50′ E | 86 | 18 |
| 939 | 11 | ,, ,, | 86 | 13 |
| 940 | 11 | ,, ,, | 83 | 6 |
| 941 | 11 | ,, ,, | 86 | *16* |
| 942 | 11 | ,, ,, | 90 | *8* |
| 943 | 15 | 61° 56′ S, 87° 29′ E | 87 | 12 |
| 944 | 17 | 62° 00′ S, 87° 30′ E | 87 | 8 |
| 945 | 18 | 61° 56′ S, 87° 45′ E | 86 | — |
| 946 | 18 | ,, ,, | 81 | 16 |
| 947 | 19 | 61° 58′ S, 88° 21′ E | 83 | *2* |
| 948 | 19 | ,, ,, | 80 | *2* |
| 949 | 19 | ,, ,, | 83 | 6 |
| | 1936 | | | |
| 950 | Jan. 19 | 61° 58′ S, 88° 21′ E | 87 | *16* |
| 951 | 19 | ,, ,, | 78 | *18* |
| 952 | 20 | 62° 01′ S, 88° 02′ E | 82 | 11 |
| 953 | 21 | 61° 46′ S, 88° 06′ E | 80 | 4 |
| 954 | 21 | ,, ,, | 80 | *15* |
| 955 | 22 | 61° 53′ S, 88° 00′ E | 88 | *13* |
| 956 | 22 | ,, ,, | 85 | 10 |
| 957 | 25 | 61° 44′ S, 87° 23′ E | 89 | 19 |
| 958 | 26 | 61° 53′ S, 87° 32′ E | 79 | 19 |
| 959 | 26 | ,, ,, | 89 | 15 |
| 960 | 28 | 62° 16′ S, 87° 52′ E | 88 | *18* |
| 961 | Feb. 2 | 64° 56′ S, 87° 44′ E | 90 | *18* |
| 962 | 2 | ,, ,, | 79 | *19* |
| 963 | 13 | 65° 26′ S, 87° 46′ E | 80 | *1* |
| 964 | 13 | ,, ,, | 82 | — |
| 965 | 13 | ,, ,, | 79 | 1 |
| 966 | 14 | 65° 24′ S, 88° 33′ E | 83 | *10* |
| 967 | 15 | ,, 88° 16′ E | 88 | *22* |
| 968 | 15 | ,, ,, | 93 | 16 |
| 969 | 15 | ,, ,, | 89 | — |
| 970 | 18 | 65° 06′ S, 88° 22′ E | 80 | 19 |
| 971 | 19 | 65° 04′ S, 88° 08′ E | 79 | *6* |
| 972 | 19 | ,, ,, | 78 | 25 |
| 973 | 19 | ,, ,, | 85 | *16* |
| 974 | 19 | ,, ,, | 83 | *10* |
| 975 | 19 | ,, ,, | 84 | *17* |
| 976 | 19 | ,, ,, | 90 | *12* |
| 977 | 20 | 65° 19′ S, 88° 15′ E | 82 | *12* |
| 978 | 21 | 65° 41′ S, 87° 45′ E | 92 | 7 |
| 979 | 22 | 65° 30′ S, 86° 52′ E | 90 | *12* |
| 980 | 23 | 65° 26′ S, 86° 30′ E | 86 | 17 |
| 981 | 23 | ,, ,, | 88 | *26* |
| 982 | 23 | ,, ,, | 91 | 13 |
| 983 | 24 | 65° 17′ S, 86° 09′ E | 89 | 9 |
| 984 | 24 | ,, ,, | 81 | — |
| 985 | 25 | 65° 19′ S, 85° 50′ E | 82 | 9 |
| 986 | 26 | 65° 17′ S, 84° 30′ E | 78 | 1 |
| 987 | 28 | 65° 35′ S, 83° 58′ E | 82 | *17* |
| 988 | 29 | 65° 30′ S, 84° 10′ E | 86 | 9 |
| 989 | 29 | ,, ,, | 79 | 20 |
| 990 | Mar. 1 | 65° 25′ S, 84° 00′ E | 82 | 1 |
| 991 | 3 | 65° 04′ S, 82° 25′ E | 87 | 24 |
| 992 | 4 | 65° 11′ S, 82° 37′ E | 79 | 9 |
| 993 | 4 | ,, ,, | 88 | *2* |
| 994 | 5 | 65° 07′ S, 81° 32′ E | 91 | — |
| 995 | 8 | 64° 40′ S, 80° 40′ E | 90 | 20 |
| 996 | 9 | 64° 37′ S, 81° 13′ E | 86 | *6* |
| 997 | 10 | 64° 39′ S, 81° 56′ E | 81 | 6 |
| 998 | 11 | 64° 35′ S, 83° 19′ E | 82 | 9 |

### *Fl.F. 'Hektoria'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| | 1936 | | | | | 1936 | | | |
| 1453 | Jan. 21 | 61° 04′ S, 28° 04′ E | 87 | *5* | 1475 | Feb. 24 | 66° 44′ S, 26° 39′ E | 86 | *12* |
| 1454 | 23 | 61° 19′ S, 28° 23′ E | 96 | *11* | 1476 | 26 | 66° 58′ S, 27° 41′ E | 82 | *2* |
| 1455 | 25 | 61° 22′ S, 28° 07′ E | 86 | *9* | 1477 | 26 | ,, ,, | 85 | — |
| 1456 | 26 | 61° 30′ S, 28° 24′ E | 89 | 28 | 1478 | Mar. 1 | 67° 29′ S, 27° 30′ E | 81 | 7 |
| 1457 | 28 | 62° 09′ S, 28° 37′ E | 81 | 11 | 1479 | 1 | ,, ,, | 89 | *12* |
| 1458 | 31 | 62° 23′ S, 28° 24′ E | 78 | 0 | 1480 | 1 | ,, ,, | 84 | *12* |
| 1459 | Feb. 5 | 62° 34′ S, 26° 39′ E | 86 | 13 | 1481 | 1 | 67° 29′ S, 27° 30′ E | 95 | *22* |
| 1460 | 5 | ,, ,, | 78 | 0 | 1482 | 1 | ,, ,, | 91 | *14* |
| 1461 | 5 | ,, ,, | 87 | *21* | 1483 | 3 | 67° 31′ S, 24° 58′ E | 93 | *18* |
| 1462 | 6 | 62° 08′ S, 26° 43′ E | 81 | *2* | 1484 | 3 | ,, ,, | 79 | 0 |
| 1463 | 10 | 62° 04′ S, 26° 49′ E | — | *9* | 1485 | 3 | ,, ,, | 86 | 9 |
| 1464 | 11 | 62° 13′ S, 26° 37′ E | 81 | 1 | 1486 | 4 | 67° 22′ S, 24° 32′ E | 82 | *9* |
| 1465 | 11 | ,, ,, | 84 | *13* | 1487 | 4 | ,, ,, | 84 | *15* |
| 1466 | 18 | 64° 56′ S, 27° 57′ E | 80 | 0 | 1488 | 6 | 67° 39′ S, 26° 11′ E | 86 | *13* |
| 1467 | 18 | ,, ,, | 79 | *1* | 1489 | 6 | ,, ,, | 86 | 2 |
| 1468 | 19 | 64° 33′ S, 27° 52′ E | 82 | *20* | 1490 | 6 | ,, ,, | 84 | 8 |
| 1469 | 20 | 64° 35′ S, 27° 18′ E | 81 | *4* | 1491 | 7 | 67° 14′ S, 26° 17′ E | 85 | 6 |
| 1470 | 20 | ,, ,, | 88 | *11* | 1492 | 9 | 67° 03′ S, 26° 54′ E | 91 | *18* |
| 1471 | 20 | ,, ,, | 80 | *2* | 1493 | 9 | ,, ,, | 85 | — |
| 1472 | 22 | 64° 32′ S, 26° 30′ E | 80 | 1 | 1494 | 10 | 67° 04′ S, 26° 26′ E | 85 | *2* |
| 1473 | 22 | ,, ,, | 79 | 0 | 1495 | 12 | 66° 54′ S, 26° 15′ E | 86 | 7 |
| 1474 | 24 | 66° 44′ S, 26° 39′ E | 85 | *13* | 1496 | 14 | 67° 52′ S, 24° 18′ E | 86 | 7 |

## 1935–6

### *Fl.F. 'Tafelberg'*

| Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea | Serial no. | Date of capture | Ship's position | Length of whale | No. of corpora lutea |
|---|---|---|---|---|---|---|---|---|---|
| | 1935 | | | | | 1936 | | | |
| 1601 | Dec. 6 | 58° 58′ S, 30° 00′ E | 84 | 15 | 1649 | Jan. 31 | 65° 17′ S, 49° 29′ E | 81 | *7* |
| 1602 | 7 | 59° 22′ S, 30° 38′ E | 82 | 8 | 1650 | Feb. 1 | ,, ,, | 85 | *7* |
| 1603 | 9 | 59° 23′ S, 30° 58′ E | 80 | 4 | 1651 | 1 | 65° 25′ S, 47° 24′ E | 79 | 5 |
| 1604 | 11 | 60° 05′ S, 31° 01′ E | 82 | *9* | 1652 | 2 | ,, ,, | 78 | 3 |
| 1605 | 14 | 60° 18′ S, 35° 12′ E | 83 | 0 | 1653 | 3 | 65° 31′ S, 45° 17′ E | 89 | 4 |
| 1606 | 17 | 60° 26′ S, 36° 41′ E | 79 | *1* | 1654 | 3 | ,, ,, | 85 | 9 |
| 1607 | 18 | 60° 26′ S, 36° 41′ E | 82 | 2 | 1655 | 4 | 65° 45′ S, 47° 24′ E | 87 | *21* |
| 1608 | 19 | 60° 59′ S, 37° 23′ E | 78 | 4 | 1656 | 4 | 65° 45′ S, 44° 42′ E | 80 | 1 |
| 1609 | 20 | 61° 40′ S, 39° 21′ E | 79 | 3 | 1657 | 5 | 65° 55′ S, 45° 49′ E | 84 | 1 |
| 1610 | 21 | 61° 51′ S, 39° 55′ E | 80 | 11 | 1658 | 6 | 65° 59′ S, 42° 51′ E | 79 | 17 |
| 1611 | 22 | 62° 04′ S, 40° 46′ E | 83 | *13* | 1659 | 7 | ,, ,, | 83 | *7* |
| 1612 | 23 | 62° 19′ S, 41° 25′ E | 81 | 3 | 1660 | 8 | 65° 35′ S, 40° 58′ E | 81 | 2 |
| 1613 | 24 | 63° 00′ S, 42° 11′ E | 84 | *21* | 1661 | 9 | 65° 51′ S, 40° 20′ E | 91 | *8* |
| 1614 | 25 | 63° 23′ S, 41° 49′ E | 78 | 29 | 1662 | 10 | 66° 36′ S, 39° 42′ E | 78 | 0 |
| 1615 | 26 | ,, ,, | 83 | 9 | 1663 | 10 | ,, ,, | 87 | *2* |
| 1616 | 27 | 63° 40′ S, 42° 06′ E | 84 | *16* | 1664 | 11 | 66° 26′ S, 39° 00′ E | 87 | 0 |
| 1617 | 28 | 63° 32′ S, 42° 53′ E | 85 | 27 | 1665 | 12 | 66° 26′ S, 39° 00′ E | 90 | 12 |
| 1618 | 29 | — | 81 | 8 | 1666 | 13 | 66° 34′ S, 38° 00′ E | 82 | *23* |
| 1619 | 30 | 63° 40′ S, 43° 46′ E | 89 | *20* | 1667 | 14 | 66° 34′ S, 37° 02′ E | 83 | 0 |
| 1620 | 31 | 64° 00′ S, 45° 00′ E | 79 | *7* | 1668 | 15 | 66° 43′ S, 39° 49′ E | 88 | **23** |
| | 1936 | | | | 1669 | 16 | 66° 20′ S, 33° 15′ E | 84 | *17* |
| 1621 | Jan. 2 | 63° 41′ S, 47° 14′ E | 82 | *13* | 1670 | 17 | 66° 21′ S, 33° 40′ E | 89 | 9 |
| 1622 | 3 | 63° 52′ S, 48° 00′ E | 78 | 0 | 1671 | 18 | 66° 21′ S, 33° 40′ E | 81 | *2* |
| 1623 | 4 | 63° 28′ S, 48° 34′ E | 86 | 25 | 1672 | 19 | 66° 17′ S, 30° 28′ E | 82 | *1* |
| 1624 | 5 | 63° 29′ S, 49° 46′ E | 86 | *16* | 1673 | 20 | 67° 04′ S, 31° 19′ E | 81 | 10 |
| 1625 | 6 | 63° 24′ S, 50° 11′ E | 80 | 1 | 1674 | 21 | 67° 04′ S, 31° 04′ E | 82 | 0 |
| 1626 | 7 | 65° 26′ S, 50° 10′ E | 81 | 1 | 1675 | 22 | 67° 06′ S, 30° 39′ E | 84 | *17* |
| 1627 | 8 | 63° 35′ S, 50° 34′ E | 79 | 14 | 1676 | 23 | 67° 06′ S, 30° 39′ E | 83 | 1 |
| 1628 | 9 | 63° 52′ S, 50° 11′ E | 88 | 3 | 1677 | 24 | 67° 07′ S, 28° 00′ E | 93 | 9 |
| 1629 | 12 | 64° 46′ S, 48° 17′ E | 86 | *21* | 1678 | 25 | 66° 59′ S, 26° 34′ E | 88 | *16* |
| 1630 | 13 | 64° 37′ S, 46° 31′ E | 86 | *7* | 1679 | 26 | 66° 44′ S, 26° 14′ E | 87 | *14* |
| 1631 | 14 | 64° 24′ S, 44° 26′ E | 80 | *3* | 1680 | 27 | 66° 44′ S, 25° 04′ E | 85 | 15 |
| 1632 | 15 | 64° 26′ S, 46° 38′ E | 81 | 4 | 1681 | 28 | 66° 51′ S, 24° 43′ E | 87 | *10* |
| 1633 | 16 | 64° 17′ S, 47° 45′ E | 85 | *13* | 1682 | 29 | 67° 55′ S, 24° 13′ E | 88 | *15* |
| 1634 | 17 | 64° 27′ S, 47° 45′ E | 80 | *2* | 1683 | Mar. 1 | 67° 59′ S, 23° 01′ E | 83 | *17* |
| 1635 | 18 | ,, ,, | 84 | 3 | 1684 | 2 | ,, 23° 33′ E | 80 | *7* |
| 1636 | 19 | 64° 21′ S, 46° 18′ E | 84 | *5* | 1685 | 3 | 67° 50′ S, 24° 04′ E | 81 | 2 |
| 1637 | 20 | 63° 51′ S, 50° 32′ E | 83 | *2* | 1686 | 4 | 67° 25′ S, 26° 14′ E | 90 | — |
| 1638 | 20 | ,, ,, | 86 | 8 | 1688 | 5 | 67° 50′ S, 26° 23′ E | 91 | *16* |
| 1639 | 21 | 64° 12′ S, 51° 06′ E | 80 | 23 | 1689 | 6 | 67° 22′ S, 27° 48′ E | 83 | 5 |
| 1640 | 22 | 65° 30′ S, 52° 00′ E* | 82 | 0 | 1690 | 7 | 67° 01′ S, 29° 10′ E | 87 | *1* |
| 1641 | 23 | ,, ,, | 80 | *10* | 1691 | 8 | 66° 28′ S, 29° 14′ E | 80 | *3* |
| 1642 | 24 | ,, ,, | 90 | 11 | 1692 | 9 | 66° 35′ S, 28° 00′ E | 83 | *7* |
| 1643 | 25 | ,, ,, | 80 | 20 | 1693 | 10 | 66° 38′ S, 27° 57′ E | 79 | 10 |
| 1644 | 26 | 64° 30′ S, 52° 36′ E | 87 | 22 | 1694 | 11 | 66° 40′ S, 27° 27′ E | 86 | *6* |
| 1645 | 27 | 64° 33′ S, 52° 28′ E | 79 | 8 | 1695 | 12 | 67° 32′ S, 26° 48′ E | 83 | 10 |
| 1646 | 28 | 64° 37′ S, 51° 23′ E | 81 | *4* | 1696 | 13 | 67° 39′ S, 26° 00′ E | 85 | *21* |
| 1647 | 29 | 64° 26′ S, 52° 41′ E | 78 | 0 | 1697 | 14 | 68° 40′ S, 23° 04′ E | 87 | 5 |
| 1648 | 30 | 65° 01′ S, 51° 41′ E | 80 | 5 | 1698 | 15 | ,, ,, | 84 | *10* |

* Approximately.

OCT 1955
LIBRARY
POFI
FISH & WILDLIFE
SERVICE

Oahu Prison